MANUAL OF CIVIL DEFENCE: Vol. I

PAMPHLET No. 1

Nuclear Weapons

CIVIL
CD
DEFENCE

PUBLISHED FOR THE HOME OFFICE
AND SCOTTISH HOME DEPARTMENT BY
HER MAJESTY'S STATIONERY OFFICE

PRICE 2*s* 6*d.* NET

HOME OFFICE
SCOTTISH HOME DEPARTMENT

MANUAL OF CIVIL DEFENCE
Volume I
PAMPHLET No. 1

NUCLEAR WEAPONS

LONDON
HER MAJESTY'S STATIONERY OFFICE
1959

First published 1956
Second Edition 1959
Second Impression 1963

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NUCLEAR WEAPONS

Preface

1. This is a revised edition of the pamphlet entitled Nuclear Weapons* which was published in 1956.

2. The 1956 edition described the general effects of a "nominal" atomic bomb and of "10 megaton"† hydrogen bomb. It was based on information available in 1955. At that time no data were available for inclusion on weapons of intermediate power, more appropriate to the type of target likely to be engaged in war. The present edition not only fills that gap but includes more reliable information which has since become available from British and American trials of a variety of nuclear weapons of different types and powers. It reviews the effects of nuclear detonations and of the basic principles for self preservation by the individual. It is intended primarily for use by civil defence instructors and trainees but it is hoped that it will be read by other members of the public. Knowledge of the basic facts and of what to do in such a catastrophe as nuclear war could save countless lives from otherwise certain death.

3. For those readers who want more technical information than is given in the present pamphlet, the following authoritative publications are recommended:—

"The Effects of Nuclear Weapons" issued by the U.S. Atomic Energy Commission in June 1957 and available from H.M. Stationery Office (price 18s.).

"The Hazards to Man of Nuclear and Allied Radiations" issued by the Medical Research Council in June 1956 and published by H.M. Stationery Office, Cmd. 9780 (price 5s. 6d.).

4. In a pamphlet covering a wide range of nuclear weapon effects, a certain amount of repetition is inevitable: to aid the student of civil defence frequent cross references are made to other relevant paragraphs. In the numbering of the paragraphs, the first figure denotes the chapter number and the second figure, or figures, the number of the paragraph in that chapter.

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* Manual of Civil Defence, Vol. I, Pamphlet No. 1, published by H.M. Stationery Office.

† For definitions of weapon power see paragraph 1.10.

CHAPTER I

General Features of Nuclear Weapons

Introduction

1.1 Conventional weapons contain chemical high explosives and on detonation energy is released as a result of chemical changes. The atoms of carbon, hydrogen, oxygen and nitrogen originally combined in the H.E. are released unchanged but recombine with other partners to form the waste products of the explosion.

1.2 Weight for weight, nuclear explosives liberate vastly greater amounts of energy than conventional explosives and this energy comes from the inner core or nucleus of each atom. In nuclear explosions, measurable quantities of matter are converted into energy but only a few of the known elements have atoms capable of releasing large quantities of nuclear energy.

Fission (or atomic) weapons

1.3 The large atoms of the heavy metals plutonium (made artificially in an atomic pile) and uranium can split into two not quite equal parts, a process which is called FISSION. This is the process which takes place in the explosion of atomic weapons.

Fusion (or hydrogen) weapons

1.4 Another process by which nuclear energy can be released is called FUSION, because certain kinds of hydrogen atoms (called deuterium and tritium) can fuse together at temperatures of millions of degrees Centigrade. This is nearly as hot as the centre of the sun but such temperatures are attained in the detonation of an atomic fission weapon. Fusion or hydrogen weapons therefore need a small atomic or fission charge as an initiator and for this reason they are sometimes known as fission-fusion devices and are classed as THERMONUCLEAR weapons.

1.5 For equal weights of nuclear explosive charge, the fusion or H-bomb releases about two-and-half times as much energy as the fission or atomic bomb. Another important difference is that the size of a purely fission-type bomb is limited because, above a certain critical size, a lump of fissile material is self-disruptive. A fusion or hydrogen bomb on the other hand has no theoretical limit to its size other than convenience in delivery on to the target. It is possible also to have a fission-fusion-fission type of thermonuclear weapon in which a fusion or hydrogen bomb containing a core of fissile Uranium-235 as an initiator is encased in a heavy container of Uranium-238. This U-238 casing also undergoes fission from the high speed neutrons produced in the hydrogen fusion detonation (see Appendix 1, paragraph 14), and since the casing might be many times heavier than the fissile core of U-235, correspondingly larger quantities of fission products would be released as fall-out from such a weapon.

1.6 Some knowledge of the structure of atoms helps towards an understanding of nuclear weapons and their effects: moreover, it is difficult to describe some aspects of these weapons without using scientific terms like isotopes, neutrons, electrons, etc. Appendix 1 contains brief notes on the structure of matter, on fission reactions and critical sizes of fissile materials and on thermonuclear fusion reactions.

Energy distribution in a nuclear detonation

1.7. The large quantities of nuclear energy released in a detonation on or near ground level are distributed approximately in the following way:—

45 per cent. in the form of blast and shock waves
35 per cent. as light and heat radiation
5 per cent. as initial nuclear radiations
15 per cent. as residual radiation from fission products.

1.8 Blast and shock waves, and to a lesser extent light and heat flash, are effects common to both conventional H.E. and nuclear detonations. Nuclear radiations are new effects in warfare peculiar to nuclear weapons. The initial radiations include the instantaneous radiation and, by general acceptance, all nuclear radiations emitted within a minute of the detonation. The residual radiation comes from radioactive fission products which, together with the other contents of the bomb, are vaporised by the intense heat in the fire-ball; when they condense on particles of debris or dust, these particles will fall to the ground as radioactive FALL-OUT over an extensive area. The residual radiation decays rapidly at first, but more slowly with time, and it may continue to be a hazard for a long period.

Weapon sizes, bomb power or yield

1.9 The power of a nuclear weapon is the total amount of energy released on detonation including all the forms of energy mentioned in paragraph 1.7, and weapons can now be "tailor made" with varying powers to cause the maximum damage to any particular size and type of target.

1.10 Quantities of energy are probably most familiar to householders in terms of the electrical unit, the kilowatt-hour (one good electric fire burning for one hour) or of the heat unit the therm which is about 29 times larger than the KWHr. A unit about a million times larger than the KWHr. is needed to express the vast quantities of energy released in the detonation of an atomic bomb. The most convenient and appropriate one is the energy released by the detonation of 1,000 tons of T.N.T. which is called the kiloton (KT) unit. The advent of thermonuclear hydrogen bombs made it desirable to use a unit about 1,000 times larger still and the megaton (MT) unit was adopted: it is equivalent to the energy released by the detonation of 1,000,000 tons of T.N.T.

1.11 The bombs dropped on Hiroshima and Nagasaki had a power of about 20 KT which was subsequently referred to as a "nominal" atomic bomb. In recent years trials have been reported with thermonuclear weapons of up to about 15 MT in power, but there are relatively few potential targets in the world which would justify the use of so powerful a weapon.

1.12 In this pamphlet the term kiloton is reserved for those weapons below 500 KT in power and more powerful types are referred to as megaton weapons, e.g. a 500 KT weapon is classed as a half-megaton (½ MT) weapon. In later chapters the distances at which specific effects are likely to be produced have been tabulated for weapons of the following powers:—

20 KT, 100 KT, ½ MT, 1 MT, 2 MT, 5 MT and 10 MT.

The fireball and the cloud

1.13 The contents of a nuclear weapon are vaporised in the luminous fireball which rapidly expands and cools to form the familiar radioactive mushroom cloud and stem. The fireball on expansion becomes lighter than the surrounding atmosphere and it starts to shoot upward at speeds which may reach 200 to 300 miles per hour. Its maximum size, its duration as a luminous fireball, the speed at which it will rise and the height to which the cloud will ascend, depend upon the power of the weapon and to some extent upon the height of burst and the prevailing meteorological conditions.

1.14 The temperature of the air falls gradually with increasing altitude and at a height, in northern temperate latitudes, of about 35,000 to 40,000 ft. there is a region called the tropopause where the temperature remains constant at about −60°C: above this is the stratosphere. The cloud produced by the detonation of a KT weapon, if it does reach the tropopause, will not penetrate far but will flatten out into the well-known mushroom shape. The clouds from MT weapons, on the other hand, may penetrate the tropopause and rise to heights of 20 miles or more into the stratosphere, depending upon the power of the weapon.

Types and heights of burst

1.15 The effects produced by the detonation of a nuclear weapon can vary considerably according to the height at which it is burst. Nuclear weapons may be fused to burst:—

(*a*) on or near the ground;

(*b*) in shallow water in a harbour, lake or river, or in deep water at sea;

(*c*) high in the air.

For each weapon of specific power there is a critical height of burst above which the fireball will not touch the ground and, hence, it will not produce appreciable contamination on the ground beneath it. The critical heights for a range of weapon powers are shown in Table 1.

TABLE 1

Power of bomb	*Maximum height for contaminating burst (in feet)*
20 KT	600
100 KT	1,100
½ MT	2,200
1 MT	2,900
2 MT	3,800 (about ¾ mile)
5 MT	5,400 (about 1 mile)
10 MT	7,200 (about 1⅓ miles)

Ground bursts

1.16 A ground burst is one in which the weapon is detonated below the critical height, i.e. either on the ground or at such a low altitude that an appreciable part of the fireball touches the surface beneath it. As the fireball shoots upward it not only carries up with it much vaporised material, but it leaves behind a partial vacuum and this causes a strong wind directed inwards and upwards towards the centre of the fireball. As this wind speed may be 200 or more miles per hour it will carry with it large quantities of dust and debris on which the radioactive fission products can condense, and these radioactive particles will be ultimately deposited on the ground as fall-out.

1.17 Large pieces of debris and particles of over 2 millimetres in size will probably fall in the vicinity of the crater: smaller particles, carried to various altitudes in the cloud, will fall at lower speeds which will depend upon their size and shape, and in falling they will be carried along by the prevailing winds, which may differ considerably both in strength and direction at different height levels.

1.18 In a ground burst, an appreciable fraction of the total energy released is dissipated in forming a crater, and some of the initial heat and nuclear radiations will be absorbed in the material displaced and lifted from the crater. Consequently, the ranges of blast damage, of fires and skin burns and of effects from initial nuclear radiation will be less than they would be for a comparable air burst.

Water bursts

1.19 These are detonations in shallow water or at such a height that the fireball touches the water surface. Large quantities of water and bottom mud will be carried up into the fireball and when the vaporised water in the cloud reaches a high altitude, it will condense to rain and bring down with it radioactive fission products some of which may be dissolved in the rain drops. The fall-out pattern on neighbouring land will be less extensive but more intensely radioactive than from a ground burst. Wet fall-out may be also much more difficult to remove, especially from rough or porous surfaces, than the relatively dry particles which occur in fall-out from a ground burst.

1.20 A nuclear weapon may burst in deep water and, apart from the absence of mud, the effects will be similar to those from a surface burst except that a larger fraction of the total energy released will be expended in vaporising more water, in producing a shock wave through the water, and in forming surface waves. Most of the fission products will be trapped in the water near the burst and will diffuse and disperse rapidly.

Air bursts

1.21 An air burst is one in which the weapon is detonated above the critical height and the fireball is well clear of the surface beneath it. There will be very few dust particles to which the vaporised fission products can adhere and they will therefore condense to minute particles with such a low speed of fall that they will have been dispersed far and wide by the winds before they reach the ground. No significant fall-out hazard will occur from this type of burst except perhaps in places where heavy rainfall has carried down some of the fission products from the lower parts of the cloud before it has dispersed.

1.22 For every weapon there is an optimum height of burst which will produce the greatest blast effect. In kiloton weapons, this optimum height is significantly greater than the critical height at which the fireball will just touch the ground, e.g. for a 20 KT weapon the critical height is 600 ft. and the optimum height of burst is about 1,000 ft. for damage in a typical British city. The corresponding data for a 10 MT weapon are about 1·36 miles for the critical height and about 1·5 miles for the optimum height.

"Clean" and "dirty" bombs

1.23 Fission products are released by all existing types of nuclear weapon. "Dirty" bombs produce a lot and "clean" bombs produce little, the dirtiness depending upon the ratio of fission to fusion in the bomb. The dividing line between "clean" and "dirty" bombs is thus a matter of opinion, but the fission-fusion-fission type of weapon mentioned in paragraph 1.5 would be a "dirty" one.

Possible methods of attack with nuclear weapons

1.24 Weapon design has improved so much that it is possible to incorporate megaton warheads in a variety of weapons, including ballistic missiles with a range of several thousand miles. Possible means of delivery are listed below:—

- (i) Manned bombers (subsonic or supersonic).
- (ii) Long-range pilotless aircraft released from land or from ships at extreme ranges.
- (iii) Long-range guided bombs released from aircraft several hundred miles from the target.
- (iv) Ballistic missiles—IRBM's (Intermediate Range Ballistic Missiles) and ICBM's (Inter-Continental Ballistic Missiles)—released at extreme ranges from land, ships off-shore, or from submerged submarines.
- (v) Undercover methods of attack.

1.25 Missiles with wings can be guided over the whole range to the target but since they depend on air to feed the engine, to support the wing loading and to exert forces on control surfaces, they are limited in speed and height of operation and are therefore more vulnerable to counter attack than ballistic missiles. The latter can be guided into the correct direction and altitude to reach the target as long as the rocket motor is operating; thereafter they must follow a ballistic path like a shell from a gun. However, ballistic missiles travel for most of their range at altitudes of several hundred miles where there is practically no air resistance and they can reach maximum speeds of 15,000 miles per hour and average range speeds of several thousand miles per hour. Nothing has been disclosed about the accuracy of existing IRBM's or prototype ICBM's but with good equipment and an efficient guidance system, the error in the point of impact should not be greater than the extreme ranges of damage and fire from larger megaton weapons. Ballistic missiles have one weakness as weapons of war—their trajectory takes them above the earth's atmosphere, and the heating effect due to air friction on re-entry may cause them to heat up and become distorted. This can be avoided at the expense of additional complications in design and reduced size of warhead, but such weapons will remain vulnerable to the intense heat effect from a defensive nuclear missile detonated in the vicinity of the attacking weapon.

1.26 The major problems in countering attacks from IRBM's and ICBM's within the time available between launching and impact are to detect the weapon, to compute its ballistic path and to fire and detonate a defensive nuclear missile at a high altitude and close enough to its path to destroy it. These problems are being studied and may be solved as a result of further advances in radar tracking equipment and high-speed electronic computing machines.

Factors affecting an attack

1.27 The damage to life and property that might be caused by nuclear detonations would depend upon:—

(i) The bomb power, which might be anything from a few kilotons, up to the megaton range.

(ii) The type of burst, e.g. air, water or ground-burst, and where it occurred.

(iii) The prevailing meteorological conditions, i.e. wind strengths and directions at all levels through which radioactive particles might fall.

(iv) The method of attack and the time available for warning the public to take cover: this might be reduced to minutes in an attack with IRBM's or ICBM's.

(v) The protective measures taken before and after the detonation.

(vi) The knowledge of the public of nuclear hazards, and their sense of discipline and readiness to respond to official advice on protective measures.

(vii) The proficiency of all services connected with civil defence in correctly advising the public, in fighting fires and carrying out other life-saving operations.

Estimation of ranges of effects from bombs of different power

1.28 In planning civil defence operations after an attack with nuclear weapons, information would be needed for each detonation on:—

(*a*) The power or yield of the weapon.

(*b*) The time and the location, i.e. ground zero (GZ) of burst.

(*c*) The height of burst.

(*d*) The wind strengths and directions at all levels up to the top of the highest radioactive cloud.

How this information would be obtained is described in Chapter III.

1.29 When the above facts were known, simple methods would be required for estimating quickly the ranges of the various effects produced by the weapon sizes used. Such estimates would be needed to assess the overall magnitude of the civil defence problems and tasks and they would include the ranges of varying degrees of structural damage, of road blockage, of fires and skin burns and of the main fire zone as well as the ranges of lethal and sickness effects from initial radiation, and the extent of the residual radiation hazard from the subsequent fall-out pattern.

1.30 Tables showing the approximate ranges of the major effects of 20 KT, 100 KT, $\frac{1}{2}$ MT, 1 MT, 2 MT, 5 MT and 10 MT weapons are included in later chapters for ready reference. For weapons of intermediate powers, the ranges may be estimated roughly by interpolation, or they can be calculated from the simple basic principles and scaling laws from which the tables were derived (see Appendix 2).

The "inverse square" law (applies to radiation from point sources)

1.31 The intensity of radiation received by a man exposed to a single source such as the fireball of a nuclear weapon decreases rapidly the further away he is from the fireball. If the distance is doubled the intensity falls to a quarter of its previous value, and if the distance is trebled it falls to a ninth, i.e. $\frac{1}{3}\times\frac{1}{3}=(\frac{1}{3})^2$. In other words, it *decreases* by a factor which is proportional to the square of the distance from the fireball. This "inverse square" law applies to all forms of radiation, light, heat initial and residual nuclear radiations (each radioactive fall-out particle can be regarded as a point source) and is one of the reasons why it is desirable to shelter in the basement or in an inner room of a house to get as far away as possible from sources of penetrating gamma radiation such as fall-out on the roof and around the outside walls.

1.32 In practice, other factors make the dose of thermal or nuclear radiation received by a man decrease more rapidly with distance than would be predicted from the "inverse square" law. For example, neutrons are absorbed by the atoms of nitrogen, gamma rays are scattered by the atoms of oxygen and nitrogen in the air, and heat radiation may be scattered or reflected back by dust particles and moisture droplets in the air: all such processes result in attenuation of the radiation. Fires and burns depend not only on the total amount of heat received but also on the rate at which it falls on a surface. These additional influences are discussed in Chapters IV and V.

Scaling laws for the effects of different bomb powers

1.33 Scaling laws have been devised for estimating the ranges at which specific effects will result from nuclear weapons of different powers. They are based on scientific principles modified by the results of field trials. The range tables in later chapters have been calculated using these scaling laws, and the known ranges of effects of 1 KT or 1 MT nuclear detonations.

1.34 Scaling laws for the more important effects of nuclear weapons are given in Appendix 2, but since most of these effects are proportional to the cube root of the weapon power this "cube root" law is outlined below.

The "cube root" law (of weapon power)

1.35 By definition the total energy released in a nuclear detonation is the power of the weapon. Thus, a 10 MT bomb is 500 times as powerful as a 20 KT bomb and so liberates 500 times as much energy in each of the forms of radiation, blast and fission products. Now the cube root of 500 or $\sqrt[3]{500}$ is nearly 8 and it has been found that the two weapons produce the same peak pressure (blast intensity) at distances from their respective explosions which differ by a factor of 8, i.e. the peak pressure at any selected distance, say 1 mile, from the 20 KT detonation will be the same as the peak pressure, at $1 \times \sqrt[3]{500}=8$ miles from the 10 MT detonation. A 1 MT weapon is 1,000 times as powerful as a 1 KT weapon and will give the same peak pressure at a distance which is $\sqrt[3]{1{,}000}=10$ times greater. In general, a detonation of W kilotons in power will give the same peak pressure as a 1 KT weapon at $\sqrt[3]{W}$ (i.e. the cube root of the power) times the distance from the centre of the explosion.

1.36 The *structural damage* caused by nuclear detonations is determined largely by the magnitude of the peak shock pressure at the point in question, but the duration of the positive phase of the shock wave also contributes to collapse in larger buildings. Both the duration of the shock wave and the time of arrival are increased by a factor of $\sqrt[3]{W}$, for a weapon of W kilotons in power, relative to those times for a 1 KT weapon, *at points where the peak pressure from each of these weapons is the same.*

1.37 Areas enclosing the same category of building damage also have radii which correspond to the "cube root" law of weapon yield and, hence, the extent of such areas can be calculated for a weapon of any given power.

1.38 The diameter of the crater from a ground-burst weapon also scales in accordance with the "cube root" law but more complicated scaling laws are necessary for the depth of the crater, the maximum size of the fireball, the dimensions of the the radioactive cloud after it has become stabilised (i.e. stopped ascending) and the effects of different wind speeds on the shape of the fall-out pattern. These are given in Appendix 2 and where possible they have been incorporated in the range tables in the later chapters.

CHAPTER II

Biological Effects of Nuclear Radiations

Introduction

2.1 The human body is a highly complex organisation of delicate controlling mechanisms based on physical and chemical processes most of which are not yet fully understood. The primary effect of nuclear radiations is to release electrical charges within the cells of the body: these charges can interfere with one or more vital functions and cause many secondary functional disorders as well as reduced resistance to disease. Hence, correlation of cause and effect becomes difficult and sometimes impossible.

Units: roentgens and curies

2.2 The curie unit is a measure of the quantity of radioactive matter and the roentgen unit is a measure of the *total* amount of radiation received by any particular object. The intensity of radiation or dose-rate at any moment is measured in roentgens per hour or r.p.h. for short. Another unit of dose called the rad is becoming more common but for civil defence purposes the rad and the roentgen can be taken as equal.* Sub-units of one thousandth, e.g. the millicurie (mc) and the milliroentgen (mr); or one millionth, e.g. the microcurie, are frequently necessary, particularly in connection with internal body contamination.

2.3 As regards the magnitude of these units, the radioactivity released in a nuclear fission detonation is about 300 megacuries, i.e. 300,000,000 curies of gamma rays for *each* kiloton of bomb power (see paragraph 1.10) while at the other end of the scale a tenth of a microcurie is the maximum permissible limit which is allowed to accumulate inside the body of anyone whose work involves the use of radium.

Relation between dose-rate and deposited activity

2.4 When radioactive fall-out is deposited uniformly over a large flat, smooth area the dose-rate at 3 ft. above the surface will be about 10 r.p.h. for every curie of activity per square yard of surface. On uneven, ploughed or rough ground, bumps and ridges will absorb some of the slant rays and this relationship between dose-rate and deposit is reduced to about 6 r.p.h. per curie per square yard.

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* A curie is 3.7×10^{10} disintegrating atoms per second, originally the activity of 1 gram of radium. It is to be noted, however, that not every disintegration releases a gamma ray.

A roentgen is the dose of X or gamma rays which will produce one electrostatic unit of electricity (about 2,000,000,000 separate pairs of charges) in each cubic centimetre of air under standard conditions; this is equivalent to the absorption of 97 ergs of energy in 1 gram of human tissue. The rad (radiation absorbed dose) corresponds to an absorption of 100 ergs of energy in 1 gram of tissue.

Individual sensitivity: sub-lethal doses

2.5 Individuals differ in their sensitivity to radiation and this makes it necessary to employ statistical methods for determining biological effects. Similar methods are used in public health and insurance problems and in determining the effective or lethal doses of poisons and of chemical or biological warfare agents. For example, a few individuals are very sensitive to relatively small doses of radiation or of poisons while, at the other extreme, a few are capable of surviving heavy doses which would kill most of their kind. It is difficult, therefore, to specify the minimum dose which would kill all the individuals in a large group of the same species, but the dose which would be lethal for 50 per cent. of the group can be specified within approximate limits; this is called the LD 50 or the dose at which each individual has a fifty-fifty chance of survival.

2.6 The best estimate that can be given at present for this lethal dose of radiation to human beings is that the LD 50 lies somewhere between 350r and 500r if the dose is received within a few days and affects the whole body. This would, of course, have to be measured with an instrument in air and held close to the body: if it could be measured in the deeper tissues of the body it would be considerably less because of absorption in the body. The dose which is lethal becomes progressively larger as it is spread over weeks or months at correspondingly lower dose-rates. The reason is that the body is capable, in time, of recovering from most types of injury including those caused by radiation.

2.7 It would be of great importance, particularly in civil defence operations, to know the precise effects of radiation exposures considerably below the LD 50 and in the range of 50 to 300 roentgens. Unfortunately, the permanent effects do not become manifest for a long time after the exposure, and earlier symptoms may be obscured by the resilence of the human body in its ability to repair injury.

Relation between dose and effects

2.8 Table 2 represents the most reliable summary of available knowledge on the relation between dose and immediate sickness effects in human beings. The general effects will be similar whether the dose is received in 4 hours or is spread over several days.

TABLE 2

Immediate sickness effects of whole body ionising radiation on human beings

Note:—All exposure causes injury to the body and it should therefore be limited to the absolute minimum

Dose in roentgens	*Effects*
Up to 150	No acute effects but increasingly serious long-term hazard.
150 to 250	Nausea and vomiting within 24 hours: some incapacitation after 2 days.
250 to 350	Nausea and vomiting in under 4 hours ; symptom-free period 48 hours to 2 weeks ; some mortality will occur in 2 to 4 weeks.
350 to 600	Nausea and vomiting in under 2 hours ; heavy mortality certain in 2 to 4 weeks ; incapacitation prolonged for survivors.
Over 600	Nausea and vomiting almost immediately : mortality in 1 week.

2.9 There is general agreement among medical experts that any increase in radiation dosage to more than a few times that of the natural background (about 0·1 roentgen per year average in the U.K.) is likely to prove harmful to the genetic heritage of a population. It is, however, not yet possible to define the hazard in quantitative terms comparable to those for the other hazards of life. In peace time, nuclear power stations and the use of radioactive isotopes in medicine and industry offer many benefits, but like other new industries they present hazards for which precautions and tolerance limits have to be agreed and accepted. In the catastrophe of a nuclear war, large sections of the population would have no choice but to try to avoid or reduce the serious radiation hazard, by seeking the best possible cover during the early period of rapid decay of the radioactivity and by submitting to disciplinary control of the daily periods of outdoor exposure for some time thereafter. Under these circumstances the tolerance dose limit for civil defence workers becomes a matter of opinion based on an attempt to balance the benefits of saving life and the means of subsistence of the survivors, against the radiation injuries which might develop in these workers at a much later date.

War-time emergency dose

2.10 In the 1956 edition of "Nuclear Weapons", a dose of 25r was suggested as permissible in war-time for a single exposure (spread over a few hours) with the proviso that, if the exposure was fairly uniform over a period of 2 to 3 days, people could probably take up to about 60r without being any more liable to radiation sickness than after receiving 25r in one short spell of three or four hours. In the light of the reassessment, in Table 2, of the immediate effects of radiation and allowing for the variation in the sensitivity of individuals to radiation, it has now been agreed that a *war-time emergency dose of* 75r should apply to all persons engaged in civil defence life-saving operations. Discretion would be given to unit commanders to continue with the task in hand up to a maximum dose of 100r if the unit was not relieved beforehand. With this exception, no one but the Regional Commissioner or a person to whom he had delegated the responsibility would have authority to sanction an increase in the war-time emergency dose of 75r for any part of the forces engaged on an operation in his Region.

Recovery effect and subsequent permissible doses

2.11 Civil defence workers who receive the war-time emergency dose of 75r should not be exposed to further radiation until they have had time to recover significantly from radiation injury. Unfortunately the recovery processes in the human body are not understood, although much work on this subject is in progress throughout the world. At present, all that can be said with certainty is that, after exposure has ceased, a substantial amount of recovery takes place within a few weeks and that further doses of radiation may be taken without producing radiation sickness, but at the penalty of increased risk of long-term injury. How long it will be desirable to wait after taking a dose of 75r and before accepting the risk of a further dose, and the amount which could be then taken without incurring radiation sickness, are questions which must be decided later in the light either of further knowledge or of the prevailing war-time circumstances.

2.12 The biological effects of nuclear radiation on the whole body (i.e. all-round radiation*) may become apparent in four successive phases which are described in the following paragraphs.

Radiation sickness

2.13 Radiation sickness is caused primarily by damage to the gastro-intestinal tract and it may develop within a few hours to a day after exposure, depending on the dose received. It may last 2 to 3 days and be followed by a period of well-being and apparent recovery. On an average, radiation sickness will occur as a result of a dose above 150r. The symptoms are fatigue, nausea, indigestion, loss of appetite and, as the dose increases, these symptoms may be accompanied by vomiting, diarrhoea, possibly with blood. The time at which these symptoms occurred might indeed be the only clue to the dose that a person has received.

Delayed effects

2.14 Delayed effects are caused mainly by injury to the blood-forming system and they may appear after a latent period of up to 4 weeks according to dose, with loss of body hair and with the appearance of blood spots due to haemorrhages under the skin. No exact figure can be given for the dose which will produce these symptoms, but they may be expected in some individuals exposed to doses of between 150r and 200r and, in the lower ranges, the effects are not necessarily incapacitating.

Long-term injuries to the individual

2.15 These include anaemia, leukaemia (a form of blood cancer, with a latent period of 3 to 6 years), tumours and cancers of the bones or tissues which may develop several or many years after exposure. Premature ageing may occur with doses nearer to 400r but it is not clear if this is a direct effect of radiation or merely a consequence of the secondary effects and the reduced resistance to disease. Whether or not there is a threshold dose of radiation which must be exceeded before these long-term effects will occur is still an open question, since at doses below 100r the incidence of these effects is so small that it has not been possible to determine it in human beings. In the present state of knowledge, and for civil defence purposes, it should be assumed that there is a slightly increased risk of leukaemia and cancer as a result of doses of about 100r and that this risk will increase in proportion at higher doses.

Genetic damage

2.16 Genetic damage is caused by radiation on the reproductive organs and germ cells which transmit heritable characteristics to subsequent generations. Here it is necessary to regard a population as a whole, with a pool of transmissible characteristics. It appears that the damage caused by radiation is directly proportional to the dose whether this is all received by a few individuals or is given in smaller doses to a large number of individuals.

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* Much higher doses can be tolerated if a part of the body, in particular, a whole limb or the abdomen, is well shielded.

2.17 Until more is known about human genetics there would be a compelling need in all civil defence operations, as indeed there is in all occupations involving radiation hazards, to restrict radiation to the minimum number of people, preferably to people over the age of 35, and to the absolute minimum dosages consistent with the humanitarian tasks of rescue, life-saving and preservation of the means of subsistence of the survivors from nuclear detonations.

Radioactive strontium

2.18 Brief mention must be made here of the problem of radioactive strontium because it has attracted so much public attention. The radioactive strontium isotopes among the fission products of a nuclear weapon are Strontium 89 which has a half life (see paragraph 3.1) of about 54 days and Strontium 90 which has a half life of about 28 years. Both of these emit beta* particles but no gamma radiation; some Sr 90 may accumulate and persist in growing bone for many years but the beta particles have a very short range and they can only affect the tissue in the immediate vicinity of the bone and do not reach the reproductive cells. Radioactive strontium is *not* therefore a genetic hazard, nor is radioactive iodine which tends to accumulate in the thyroid gland in the neck and which has a relatively short half life of about 8 days. The hazard from radioactive isotopes which tend to accumulate and persist in certain body organs (see paragraph 8.12) arises primarily when contaminated food or liquid is eaten or drunk, and this is dealt with more fully in Chapter X.

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* See paragraph 6, Appendix 1.

CHAPTER III

Instruments for Detecting and Measuring the Effects of Nuclear Explosions

Radioactive decay rates: half lives of radioactive isotopes

3.1 A piece of radioactive matter the size of a pinhead contains some million, million, million atoms and it is entirely a matter of chance when any particular atom will disintegrate and decay into a stable non-radioactive form. The process of decay cannot be influenced by heat, pressure or chemical reaction but it is possible to measure its rate and to determine what fraction of the initial number of atoms present will have decayed after any chosen time. A convenient way of expressing this is the "half life", that is the time by which half of the atoms originally present will have decayed. Like the death or birth rate in a population it is independent of the size of the population (as long as this is a large number). The half life is a constant for each isotope; it is characteristic of that isotope and offers a convenient means of identifying it.

3.2 It has already been mentioned that about 200 isotopes or different radioactive species of the atoms of about 35 of the elements are released in a nuclear fission detonation. The half lives of these fission product isotopes vary from a fraction of a second to thousands of years. The rate of decay of the mixed fission products is rapid at first but it slows down in time as the shorter-lived isotopes disappear. It has been found that, from 1 hour after detonation up to about 200 days, the decay rate of all the various isotopes can be averaged in such a way that a mathematical formula* can be used to estimate the activity at any time provided its value has been measured at a known time. This formula is referred to as the "t to the minus one point two decay law". It must, however, be clearly emphasised that whilst this law may be assumed for the purposes of exercises and studies, there may well be variations and departures from it in any actual burst.

Radiac calculator and seven-tenths rule

3.3 The use of this mathematical formula for fission product decay requires logarithmic tables or a graph with a curve showing the decay of a standard unit of activity plotted against time, or the circular radiac calculator No. 1† which has instructions for use printed on the back. For many civil defence purposes the *seven-tenths rule*

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* This formula is $R_t = \frac{R_1}{t^{1.2}}$ or $R_1.t^{-1.2}$

Where R_1 is the dose-rate in r.p.h. at 1 hour after burst and R_t is the dose-rate at any later time t hours.

† The pink side only of the calculator disc should be used : the blue side is now obsolete.

enables one to make a quick approximate mental calculation of the radiation level at any time from a single measurement at a known time. This rule is that *the intensity of radiation falls by a factor of* 10 *as the time lengthens by a factor of* 7. Its application is illustrated in Table 3 for a dose rate of 100 r.p.h. measured at 1 hour after a nuclear detonation.

TABLE 3

Time after burst	*Time factor*	*Dose-rate r.p.h.*	*Dose-rate factor*
1 hour	1	100	1
1¾ hours	7/4	50	½
7 hours	7	10	1/10
2 days (49 hrs)	7×7	1	1/100
2 weeks	7×7×7	0.1	1/1,000
14 weeks	7×7×7×7	0.1	1/10,000

The 50 r.p.h. figure has been included as it is often useful to know that the dose-rate will be halved when the time is increased by a factor of 7/4.

Assembly and reporting of information about nuclear explosions

3.4 The Royal Observer Corps, which has a country-wide network of observer posts (R.O.C. posts) and protected accommodation, would be responsible for locating and measuring nuclear detonations and for reporting and tracking fall-out. On the explosion of a nuclear weapon, information from R.O.C. posts relating to the power, location and height of burst of the explosion would be transmitted via R.O.C. Group Headquarters to the appropriate Sector Operations Centre of the United Kingdom Warning and Monitoring Organisation, which would also receive six-hourly meteorological reports containing the mean wind speeds and directions from the ground up to various levels, extending to at least 80,000 ft. and, if required, to 100,000 ft. At the Sector Operations Centre, members of the Warning Organisation, in conjunction with meteorologists of the Air Ministry Meteorological Office, would process the information. This would enable a broad prediction to be made of the territory likely to be covered by fall-out and a preliminary (Grey) fall-out warning would be issued to the districts concerned wherever time permitted. Warning Officers stationed at R.O.C. Group Headquarters would also collate the information from R.O.C. posts and would issue fall-out warnings within the Royal Observer Corps Group if the Sector was unable to function. The necessary information would be passed to Civil Defence Controls so that they too would be in a position to predict the likelihood and possible limits of fall-out. In addition, local monitoring would be undertaken by the Civil Defence Corps from warden posts and similar reporting agencies.

3.5 When the radiac instruments in a R.O.C. post began to record fall-out, the time of arrival of the fall-out and (at short intervals) the dose-rate would be reported to the Sector Operations Centre via R.O.C. Group Headquarters. The Sector Operations Centre receiving such information from a number of posts would be able to plot on a map the boundaries of the advancing front of the fall-out. They would be able to correct previous predictions, to issue a "fall-out imminent" warning (Black) to the areas which would be affected and to cancel warnings previously issued to districts which would not be affected. Since the individual R.O.C. posts are several miles apart, the general broad picture of fall-out received from this network would be supplemented in greater detail from local warden posts as required.

3.6 The various instruments which have been developed for determining the position and power of a nuclear explosion (including the height of burst), for detecting radioactivity and for measuring radiation intensity are described below.

Ground zero indicator (see Plates 3 and 4)

3.7 This instrument, with which R.O.C. posts will be equipped, records the line of sight to the point of detonation, i.e. the compass bearing and elevation of the burst. From the records of such instruments at two or more posts, the height of burst and the location of ground zero below it can be determined by triangulation. It is, in effect, a simple pinhole camera in which the image of the fireball together with that of a locating grid showing bearing and elevation is photographed by the bomb flash on sensitised paper. All-round vision is secured by the cylindrical case with four pinholes at intervals of 90 degrees. The sheets of sensitised paper are held in four transparent plastic casettes concave towards each pinhole. The bearing and elevation grids are printed on the casettes and numbered for each appropriate compass quadrant. The sensitised sheets (which require no developing) should be collected as soon as possible after each detonation and to do this an observer has to come out of the underground post for one or two minutes. The instrument will be mounted on a pedestal previously erected and oriented with respect to true North.

Bomb power indicator

3.8 This instrument is under development with a view to its eventual installation in R.O.C. posts. It will consist of a bellows-operated pressure gauge with a pointer which remains at the indicated peak pressure after the passage of a shock wave: it then has to be reset by hand. From this reading of peak pressure, together with the known distance of the post from the point of burst (obtained by triangulation of bearings from the ground zero indicators), the power or yield of the bomb could be ascertained, with sufficient accuracy for civil defence purposes, from tables or graphs showing peak pressures at various distances for bombs of different powers.

Remote indicating fixed survey meter

3.9 Underground R.O.C. posts are protected against blast and nuclear radiation and would be expected to maintain a steady flow of information even if they were located relatively close to a nuclear burst or in areas of heavy fall-out. For this purpose they will be provided with remote indicating fixed survey meters to enable observers inside the post to report dose-rates above and outside the post at 5 minute or other required intervals.

3.10 This instrument is a modification of the lightweight survey meter (see paragraph 3.17) from which the ion chamber has been removed and connected to the recording instrument by a cable 16 ft. long. This ion chamber is pushed up through a 4 in. diameter pipe in the concrete roof of the underground post: the pipe extends to a height of 2 ft. above ground level and the flange at the top is surmounted by a plastic dome which extends upwards for a further 18 in. The ion chamber is pushed up into the plastic dome, which is designed to have the same blast resistance as the post. The dome protects the ion chamber from contamination by fall-out and yet remains virtually transparent to gamma radiation with no significant reduction in the measured external dose-rate.

3.11 The recording instrument has a logarithmic* scale reading from 0 to 500 roentgens per hour (r.p.h.). Before the external dose-rate rises above 500 r.p.h. it should be compared with the dose-rate measured when the probe is withdrawn inside the post. This ratio of external to internal dose-rate would be the protective factor of the post, and it would be used to calculate external dose-rates in excess of 500 r.p.h. from the dose-rates measured with the probe withdrawn inside the post. Consideration is being given to the installation of remote indicating fixed survey meters at civil defence control centres where conditions are suitable for their use.

Other radiac instruments

3.12 Instruments of several types have been designed to detect the presence of radioactivity or to measure the intensity of radiation. Most of these instruments depend on the property possessed by all nuclear radiations of ionising the air through which they pass. That means they leave behind a trace of positive and negative electrical charges which can be collected on oppositely charged electrodes. Three main types of radiac instrument have been designed especially for use in civil defence:—

(*a*) The INDIVIDUAL DOSIMETER: this measures the *total dose* of radiation received and accumulated over a given period at the place where the instrument is being used.

(*b*) The SURVEY METER: this measures the *rate* at which radiation is being received at a given time and

(*c*) The CONTAMINATION METER: this measures the degree of radioactive contamination on the person or on equipment. Special modifications of the contamination meter have been developed for detecting undesirable levels of radioactive contamination in drinking water and in liquid or solid food.

Individual dosimeter

3.13 This is a small instrument easily carried on the person: it is about the size of a fountain pen (see Plate 5). Its primary purpose is to measure the total dose of residual radiation which its user accumulates whilst operating in a contaminated area. For those who happen to be within range at the time of the explosion it will, of course, be affected also by the initial flash of nuclear radiation, but will not record the flash dose fully because of the high rate at which this is received.

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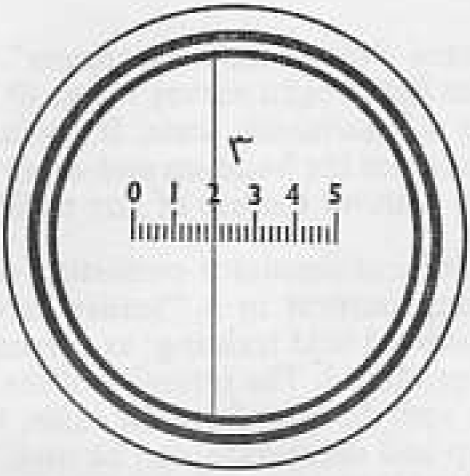
* A logarithmic scale is more open at the lower end than at the higher end and is more uniformly accurate over the whole range than is a linear scale.

3.14 Technically, the dosimeter is a quartz-fibre electroscope, since the movement of a very fine quartz fibre between charged electrodes is used to measure the ionisation of the air produced by the radiation. (The instrument may be used in a thin transparent plastic cover or tube to protect it against contamination by radioactive dust (see Plate 7). It is much easier to re-issue the instrument with a fresh cover than to attempt to decontaminate the instrument itself.) The reading is taken by applying the clip end of the instrument to the eye, pointing it towards the light and reading the position of the thin black vertical line against the scale (see Fig. 1). If a plastic cover is used, it may be necessary to uncover the eyepiece end to read the instrument in a poor light.

FIGURE 1

Individual dosimeter scale showing reading of 2 roentgens



3.15 Three main types of individual dosimeter have been developed for civil defence use; the No. 2 reading from 0 to 5 roentgen; the No. 3 reading up to 50r; and the No. 4 reading up to 150r. For training purposes a No. 1 instrument of identical appearance but having a scale reading up to 0·5r can be used with special radioactive sources.

Dosimeter charging unit

3.16 The individual dosimeter has to be charged before use in order to bring the pointer to the zero position on the scale: it is gradually discharged by the ionisation produced on irradiation so that the scale reading becomes a measure of the radiation dose. A special dynamo type of charging unit is available and this is operated by a few turns of a handle (see Plate 6). It is quite independent of batteries, an important consideration in wartime. Charging and re-charging after use would normally be done at depots and places where forces were based. It is intended that the charging unit should be made available at local controls and warden posts.

Radiac survey meters

3.17 These meters are intended for use in surveying contaminated areas so that radiological control of access and exposure could be established and maintained. Until recently two versions only were available, but a lightweight survey meter*, for use under more arduous conditions, has also been developed. Of the two earlier versions, the

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* Meter, Survey Lightweight, (AVO) Mark 3.

No. 1 has a single linear scale reading from 0 to 3 r.p.h. (see Plate 10), while the other, the No. 2, has three ranges with linear scales (0 to 3 r.p.h.; 0 to 30 r.p.h. and 0 to 300 r.p.h.) with a range selection switch (see Plate 8). The lightweight meter has a logarithmic scale (see footnote to paragraph 3.11) reading from 0 to 100 r.p.h. The No. 1 and No. 2 meters have a thin metal window which excludes beta particles when closed but when open allows a record to be made of beta plus gamma radiation: the lightweight meter has no beta window and can therefore be used only to measure gamma radiation.

Training survey meters and fall-out simulator

3.18 For training purposes an instrument almost identical in appearance to operational survey meters Nos. 1 and 2, but having a scale reading up to 300 microroentgens* per hour, is used with special radioactive sources.

3.19 A battery operated "radiac fall-out trainer" has been devised to teach users of the lightweight survey meter (0 to 100 r.p.h.) to read and report from a logarithmic scale. It lends realism to a fall-out reporting exercise since the build-up and decay of radiation intensity can be simulated without the use of any radioactive sources.

3.20 A larger radiac fall-out simulator consisting of a 5·5 kilocycles per second alternating current in a "leader cable" system has been developed for eventual field training; at present, only the prototype model has been produced. The intensity of the electromagnetic field and its variation with distance from the cable, together with a superimposed build-up and decay-rate, can be used to simulate a fall-out pattern. A detecting instrument similar in appearance and operation to the three range survey meter is used to simulate the latter.

3.21 A trainer for use at R.O.C. posts has also been designed which will produce a meter display resembling that of the fixed survey meter (see paragraphs 3.9 to 3.11). This is purely a mechanical instrument which will give readings to simulate the build-up of radioactive fall-out to a maximum, followed by decay in accordance with the decay formula mentioned in the footnote to paragraph 3.2. It will also be possible to simulate the build-up and decay of fall-out from two or more bombs.

Contamination meter

3.22 The hazard from all-round gamma radiation in an area covered with fall-out would be far greater than the risk of contact with radioactive material (see paragraphs 8.10 to 8.11); even when conducting rescue operations, a dust filter or respirator would be necessary only if the amount of dust was intolerable. The contamination meter is intended for detecting the presence of radioactive contamination on the skin, clothing or equipment of those who may have been working for some time in contaminated areas. It is now likely to be used only in hospitals to prevent contamination of operating theatres and as a monitor for drinking water. It is much too sensitive to be used against the background radiation in a fall-out area unless carefully isolated and shielded against the general field of contamination.

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* 1 microroentgen = 1 millionth roentgen.

3.23 The contamination meter consists of a Geiger counter probe connected by cable to a recording instrument (see Plate 9). For hospital use, the probe has a thick rubber case which excludes beta particles but it counts the number of atoms disintegrating per second and emitting flashes of gamma rays: this is a measure of the total radioactivity since the proportion of beta to gamma in fission products is known. For use as a water monitor, still greater sensitivity is needed because of the very low permissible safety levels and a cup-shaped probe to contain the water sample is used: the cup wall is very thin and permits a measurable proportion of the beta particles to penetrate and be counted in the probe.

CHAPTER IV

Effects of Initial Nuclear Radiations

Introduction

4.1 Nuclear radiations are continuously emitted from the moment of detonation of a nuclear weapon and for long periods thereafter. They are emitted from the fireball, from the radioactive particles in the cloud as it is dispersed by the winds, and finally from the radioactive fall-out material deposited on the ground. The division between initial (sometimes called flash) nuclear radiations and residual radiation, therefore, has been chosen arbitrarily at one minute after detonation.

4.2 *Neutrons* (see Appendix 1) and *gamma rays* are emitted instantaneously on detonation and they are followed by gamma radiation from the newly-formed and intensely radioactive fission products in the fireball. Most of the neutrons are captured by the material of the weapon but others escape.

Neutrons and induced activity

4.3 Since neutrons are fundamental particles carrying no electrical charge they are not affected by the positive nuclear charges or the surrounding clouds of negative electrons in the matter through which they pass. They are deflected or stopped only by direct collision and can therefore penetrate considerable distances through the atmosphere but fall off more rapidly than do gamma rays. For some distance around the point of detonation the neutron dose may be higher than the gamma flash dose, but beyond a certain point the gamma hazard predominates and this point is always well within the zone in which strong blast and radiation protection are needed. Thus, it may happen that the neutron hazard is greater in shelters quite close to the detonation of small tactical weapons with light cases which permit a higher proportion of the neutrons to escape. *Otherwise a shelter which gives reasonable protection from gamma radiation also gives good protection against neutrons.*

4.4 Neutrons which escape from the detonation are either captured immediately, or are slowed down and then captured, by nuclei of neighbouring atoms. When a neutron is captured by the nucleus of another atom the latter becomes unstable and radioactive. This is called "induced" activity and it will occur in the material underneath a ground or low air burst and may be mixed with fall-out, In general, activity induced in the materials of the soil decays more rapidly than the average for fission products and becomes insignificant within a few days.

4.5 An important form of induced activity with immediate instead of prolonged effect, is the capture of neutrons by the atoms of nitrogen in the atmosphere. The new nucleus is intensely radioactive and very quickly emits an extremely penetrating gamma radiation which intensifies and extends the range of the initial gamma flash.

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 distance 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

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* 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.

seen also from a comparison of the ranges in Tables 4, 6 and 11 that for megaton bombs the hazards from blast and heat effects would extend far beyond the range of possible injury from initial nuclear radiations. At Hiroshima and Nagasaki, there was no fall-out because the bombs were air-burst, but many Japanese—otherwise not seriously injured—suffered from initial gamma radiation, because the bombs were small (about 20 KT).

Shielding against initial gamma radiation: half value thicknesses of shielding materials

4.9 The initial gamma rays from a nuclear detonation are more energetic and penetrating than the residual radiation from fall-out. Both initial and residual radiations are attenuated or reduced in intensity by passage through shielding materials and to an extent which depends on the massiveness or density of the material. The thickness of shield needed to reduce the dose-rate in a beam of gamma rays by half is called the "half value" thickness of that particular shielding material. (See also paragraph 9.14 and Figure 7.)

4.10 The half value thicknesses of the commoner shielding materials (steel, concrete, earth and water) against initial gamma radiation are shown in Table 5.

TABLE 5

Shielding material	*Half value thickness against initial gamma radiation (INCHES)**
Steel	1.5
Concrete	6.0
Earth	7.5
Water	13.0

Personal protection from initial nuclear radiation

4.11 In spite of extensive research in many parts of the world no satisfactory therapy is available yet for self-injection or oral administration immediately after exposure to a lethal dose of radiation.

4.12 The only protection against initial radiation is to be under adequate shielding when the flash occurs (to escape both the direct and the scattered radiation). It must also be remembered how effectively the radiation decreases with distance from the detonation.

4.13 It must be emphasised that protective clothing provides *no* protection against gamma radiation; it only prevents radioactive dust from getting on to the skin or into the body.

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* The half value thickness against initial gamma radiation varies greatly with the way in which the bomb is constructed. The greatest thicknesses necessary are shown in Table 5.

CHAPTER V

Effects of Thermal Radiation

Introduction

5.1 Thermal radiation or heat flash consists of visible light rays, invisible ultra-violet rays of shorter wave length and invisible infra-red rays of longer wave length: these rays all travel with the speed of light. Fortunately, the ultra-violet rays, which are particularly injurious to living tissue (in milder form these effects are familiar as sunburn), are strongly absorbed in the atmosphere so that at distances where people are not killed outright by blast, the thermal radiation consists almost entirely of intense visible light and infra-red rays. It was mentioned in paragraph 1.7 that about 35 per cent. of the total energy released in a nuclear detonation is emitted in the form of light and heat radiation which can cause fires and skin burns out to considerable distances.

5.2 The intensity of the direct heat radiation received at any place may be enhanced, in a way similar to that of visible light, by reflection and scatter from clouds or from fog and dust particles in the atmosphere, or it may be reduced by absorption in passing through thick fog or heavy atmospheric pollution.

5.3 The maximum size of the fireball and the time it persists depend upon the weapon power. Appendix 2, paragraph 3 contains a formula, based on observations at weapon trials, for calculating the maximum size reached by the fireball of a weapon of any given power. The fireball from a 20 KT weapon lasts about 1½ seconds, while the fireball from a 10 MT detonation persists for at least 20 seconds although most of the heat energy is emitted during the first half of this time.

5.4 Thermal radiation like visible light is reflected by light colours and absorbed by dark ones so that dark coloured objects are more likely to catch fire than white or light coloured ones.

5.5 It has been explained (paragraphs 1.31 and 1.32) that, in a clear atmosphere, the amount of heat which would fall on a man exposed to radiation from a nuclear detonation would decrease rapidly with his distance from the fireball: it would be decreased by a factor which is the inverse of the square of that distance, i.e. if his distance is trebled he would get only one-ninth as much radiation. In practice, the atmosphere would contain some mist, dust and industrial pollution; the actual conditions at the time and his position, in relation to clouds of these substances in the air and to the fireball, would determine whether he would receive more or less radiation than would be calculated from the "inverse square" law. (When the sun is hidden most of our daylight is scattered light.) Hence, there is no simple scaling law for determining the thermal effects produced by weapons of different powers (see also paragraph 5.10 and paragraph 3 of Appendix 2).

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.

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* 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.

Fire protection and precautions

5.13 *Primary fires* would result from heat flash through windows, open doors, etc., igniting the combustible contents in houses, offices and stores. An obvious fire precaution would be to rearrange the furnishings or equipment and to remove all inflammable material out of the direct path of any heat rays that might enter through windows or other openings. Another very important precaution would be to whitewash windows and skylights as this would keep out about 80 per cent. of the heat radiation. The windows might be broken by the blast wave but as this travels more slowly it would arrive after the heat flash had passed (except of course in the central area of complete destruction where it would not matter).

5.14 The above precautions apply to windows and other openings with a direct view of some part of the sky. In a built-up area they would apply more particularly to the windows of upper floors: even from a high air burst the buildings would have a considerable shielding effect on one another.

5.15 *Secondary fires* might be the consequences of blast damage, scattering of domestic fires, rupture of gas pipes or short-circuiting of electrical wiring. These risks could be reduced if commonsense precautions were taken on receipt of a warning, such as shutting up stoves, covering open fires with sand or earth and by turning off gas and electricity at the mains.

The possibilities of a fire storm

5.16 The chief feature of a fire storm is the generation of high winds which are drawn into the centre of the fire area to feed the flames. These in-rushing winds prevent the spread of the fires outwards but ensure almost complete destruction by fire of everything within the affected area. A fire storm inevitably increases the number of casualties since it becomes impossible for people to escape by their own efforts and they succumb to the effects of suffocation and heat stroke.

5.17 The 20 KT Hiroshima bomb (but not the Nagasaki one) caused a fire storm and fire storms were caused in Hamburg* and in several other cities as a result of heavy incendiary attacks in the last war. A close study of these fire storms and of German cities in which fire storms did not occur revealed several interesting features. A fire storm occurred only in an area of substantial size (i.e. several square miles) heavily built-up with buildings containing plenty of combustible material and where at least every other building in the area had been set alight by incendiary attack.

5.18 It seems unlikely that an initial density of fires equivalent to one in every other building would be started by a nuclear explosion over a British city; studies have shown that a much smaller proportion of buildings than this would be exposed to heat flash (due to shielding). Moreover, the vulnerable centres of many British cities were destroyed in the last war and the new buildings which are replacing them are mainly of fire-resistant construction and less closely spaced. Fire storms after nuclear attack are therefore unlikely in most British cities but the risk would be greatly reduced by adopting the precautions outlined above.

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* About 1,625,000 escaped injury during the fire storm at Hamburg, although out of a population of about 1,700,000 at risk, the 35-40,000 killed represented about 10% of the whole of civilian deaths in Germany from air attack throughout the war.

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 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.

6.5 A possible civil defence problem might be that of a crater blocking a river, but since British rivers are relatively small it is unlikely that the flooding would extend beyond the area of complete destruction. Furthermore, the radioactivity in the vicinity of the crater would be so intense that no remedial operation such as cutting a channel through the crater lip, except possibly by bombing from the air, would be possible for a considerable time after the nuclear detonation.

Ground shock

6.6 The ground shock effects produced by a megaton surface burst are similar to those produced by an earthquake of moderate intensity, but the pressure in the ground shock wave falls off more rapidly with distance. The effects of this ground shock on structures above ground are irrelevant, since they do not occur beyond the distances at which these structures are totally destroyed by blast. Its effects on structures below ground depend upon the ability of the structure to accommodate itself to the accompanying ground movement. Thus, small structures (e.g. shelters below ground) would move bodily with the surrounding ground and should be undamaged beyond 2 or 3 crater radii from the burst. Similarly long, flexible underground structures (e.g. underground utilities) should be able to accommodate themselves to the comparatively small *relative* ground movement, and should be undamaged outside about 3 crater radii (i.e. less than $1\frac{1}{2}$ miles for a 10 MT bomb).

CHAPTER VII

Effects of Damage from Air Blast

Introduction

7.1 The enormous pressure produced in the detonation of a nuclear weapon gives a violent push to the surrounding air with the result that a wave of high pressure is transmitted outwards through the air; in addition, a strong wind is caused by the bulk movement of the air. The pressure wave is followed by a suction wave, i.e. a partial vacuum which then causes a wind in the reverse direction towards ground zero.

7.2 Initially, the pressure wave is transmitted at a speed considerably greater than that of sound (which is about 1,100 ft. per second) but it gradually slows down to the speed of sound at great distances. A factor of importance is that its speed also depends upon the temperature of the air through which it is transmitted and this gives rise to the *shock wave*. When the front part of the wave reaches any particular point, the air at that point is compressed and heated and the rear portion of the wave is able to move faster through the hot air and eventually catches up with the front part. The wave front then becomes steeper and almost vertical in the form illustrated in Fig. 2.

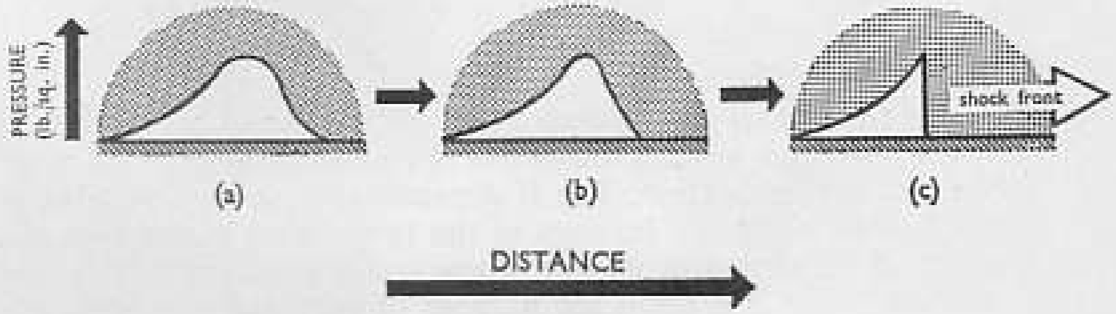

FIGURE 2

Simplified representation of development of shock front

Any obstacle in its path would experience a sharp blow due to the very sudden rise from atmospheric pressure to the peak pressure in the wave front.

7.3 Shock waves can be reflected from surfaces, a fact responsible for many freak damage effects observed in the last war. When this happens the peak pressure on the surface of the obstacle may be increased by a factor between 2 and 8 depending upon the strength of the original shock wave. The degree of damage to some buildings may be related to the blow from the shock pressure alone, and in others to the duration of the shock wave as well as to the peak shock pressure.

Mach wave

7.4 A special way in which a shock wave, travelling outwards along the ground, may be intensified is known as the MACH effect. This occurs when the blast wave from an air burst strikes and is reflected from the ground as illustrated in Figure 3. The reflected wave also moves outward through air already heated by the direct shock wave, and will catch up with the latter at some distance from ground zero to form a MACH wave in which the peak pressure is almost double that in the original shock wave.

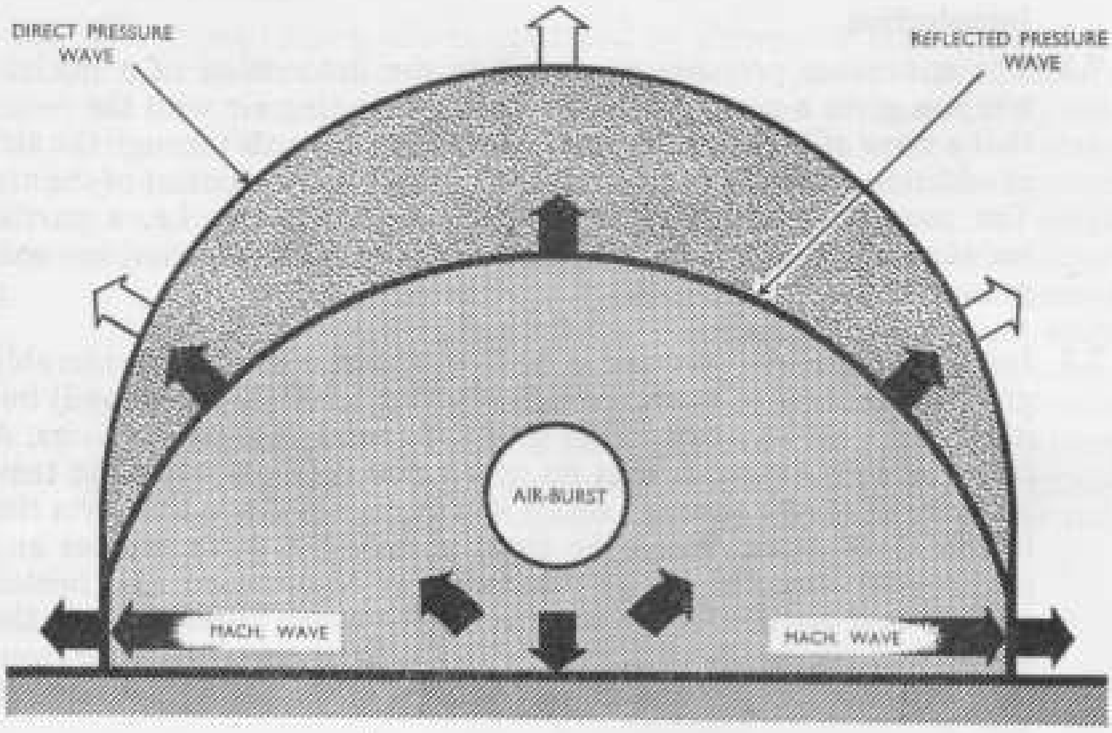

FIGURE 3
Formation of Mach wave

Structural damage

7.5 Damage to a structure depends upon the power of the bomb, on whether it is air or ground burst, and upon the distance of the structure from the detonation. But it depends also upon a number of other factors which are features of the target such as the type and strength of the structure, its size, shape and orientation with respect to the explosion and upon the number of potential openings, e.g. doors, windows and wall panels which could fail during the passage of the blast wave. The damage is the result of displacement which can be caused by two major forces exerted by the blast. These are the abrupt rise in pressure as the shock wave hits the building (and passes over it in a fraction of a second), and the drag force which is exerted by the high wind throughout the duration of the positive pressure wave and tends to distort the building or to push it over on to its side.

Shock or diffraction loading on a building

7.6 When the front of a shock wave strikes a building it is reflected and the pressure on the face towards the explosion is momentarily increased by a factor of two or more. As the main shock front moves

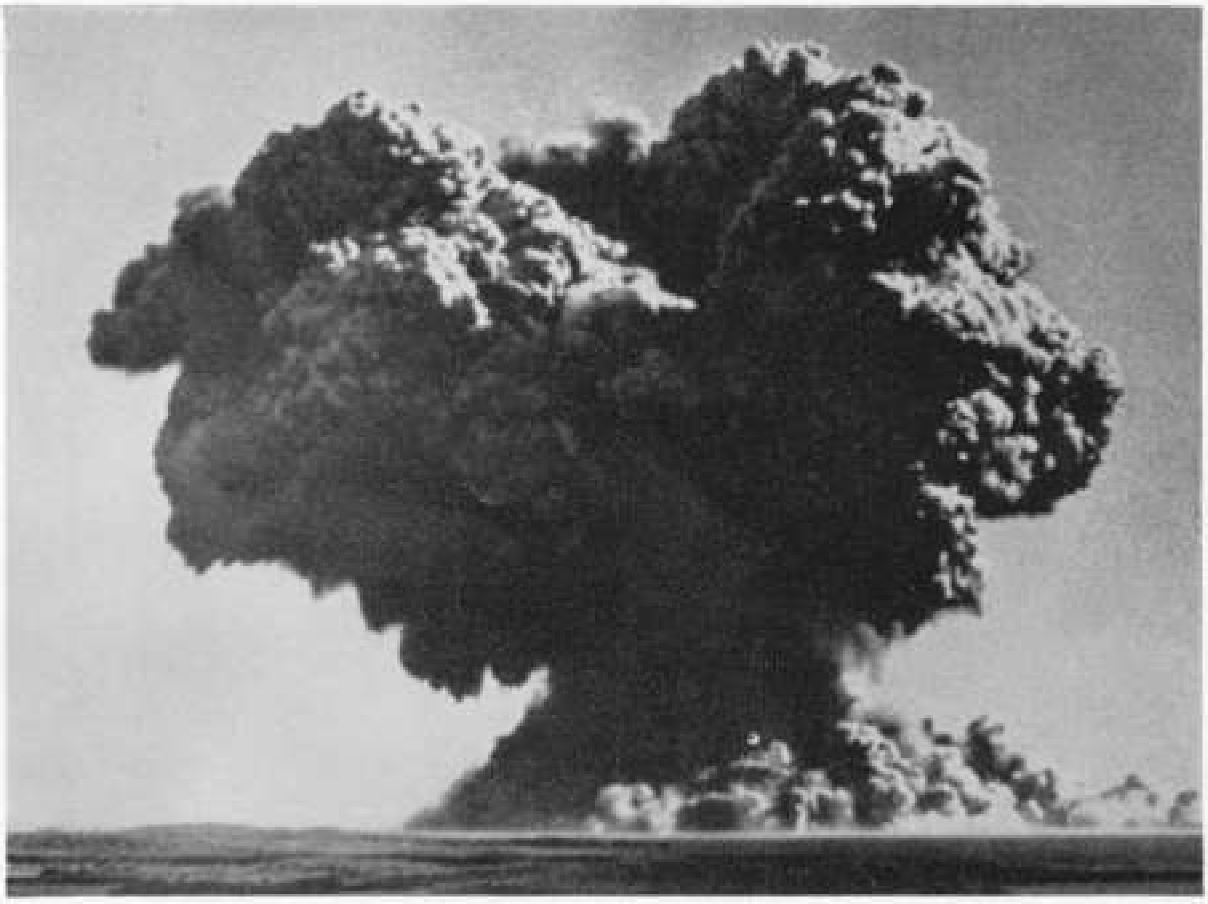

Plate 1
The first British nuclear explosion, Montebello, 1952

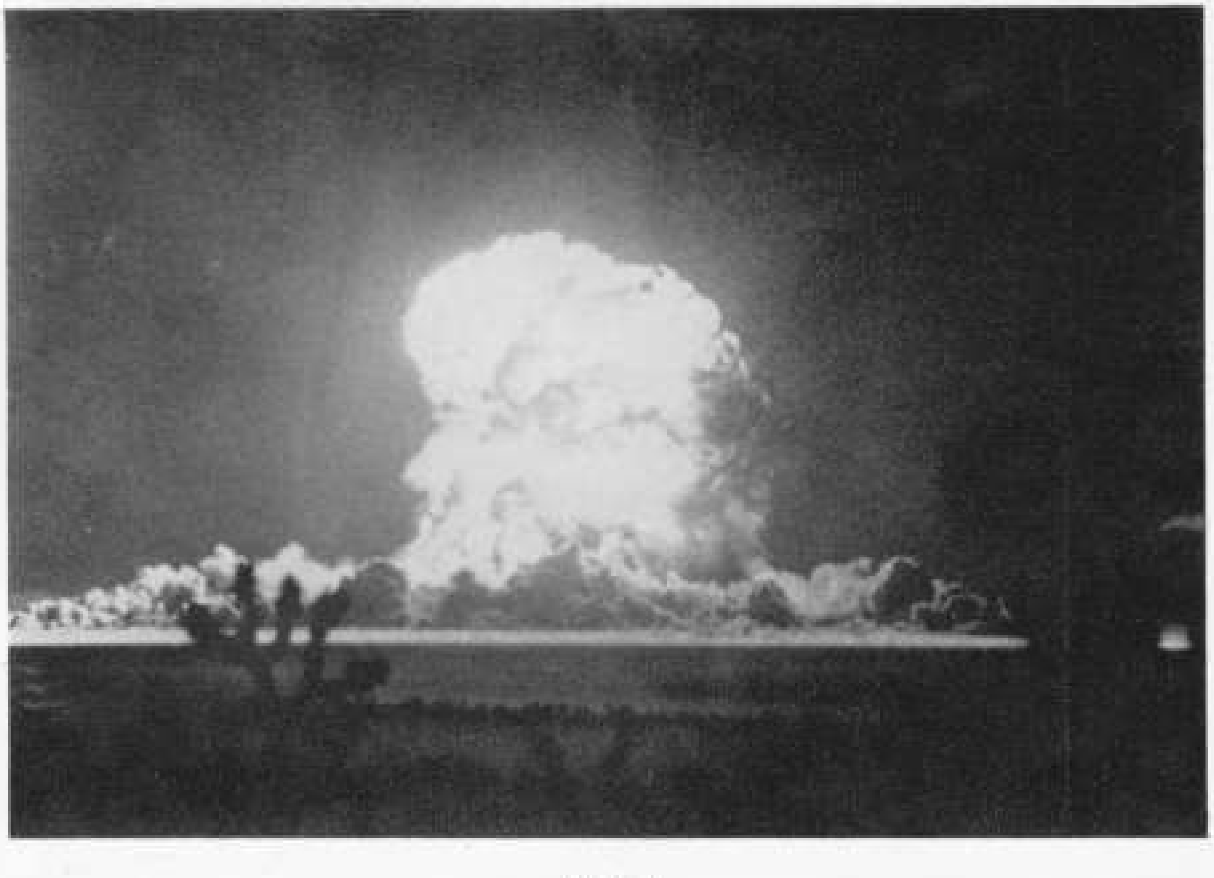

Plate 2
The fireball

Plate 3
The ground zero indicator (exterior)

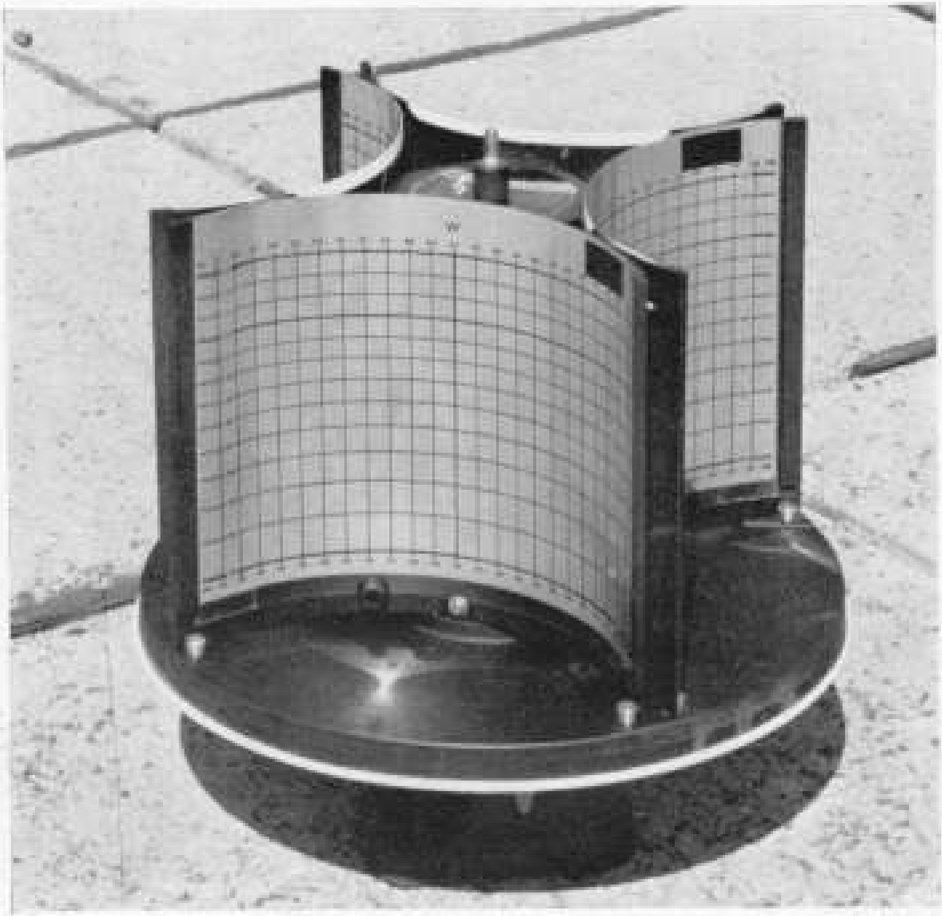

Plate 4
The ground zero indicator (showing casettes)

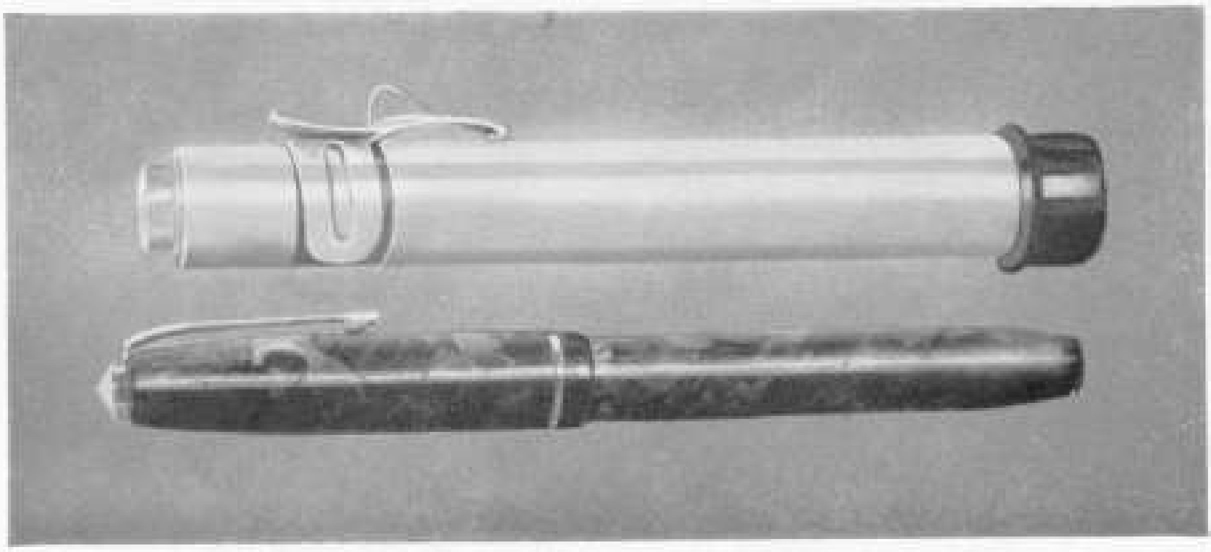

Plate 5
Individual dosimeter

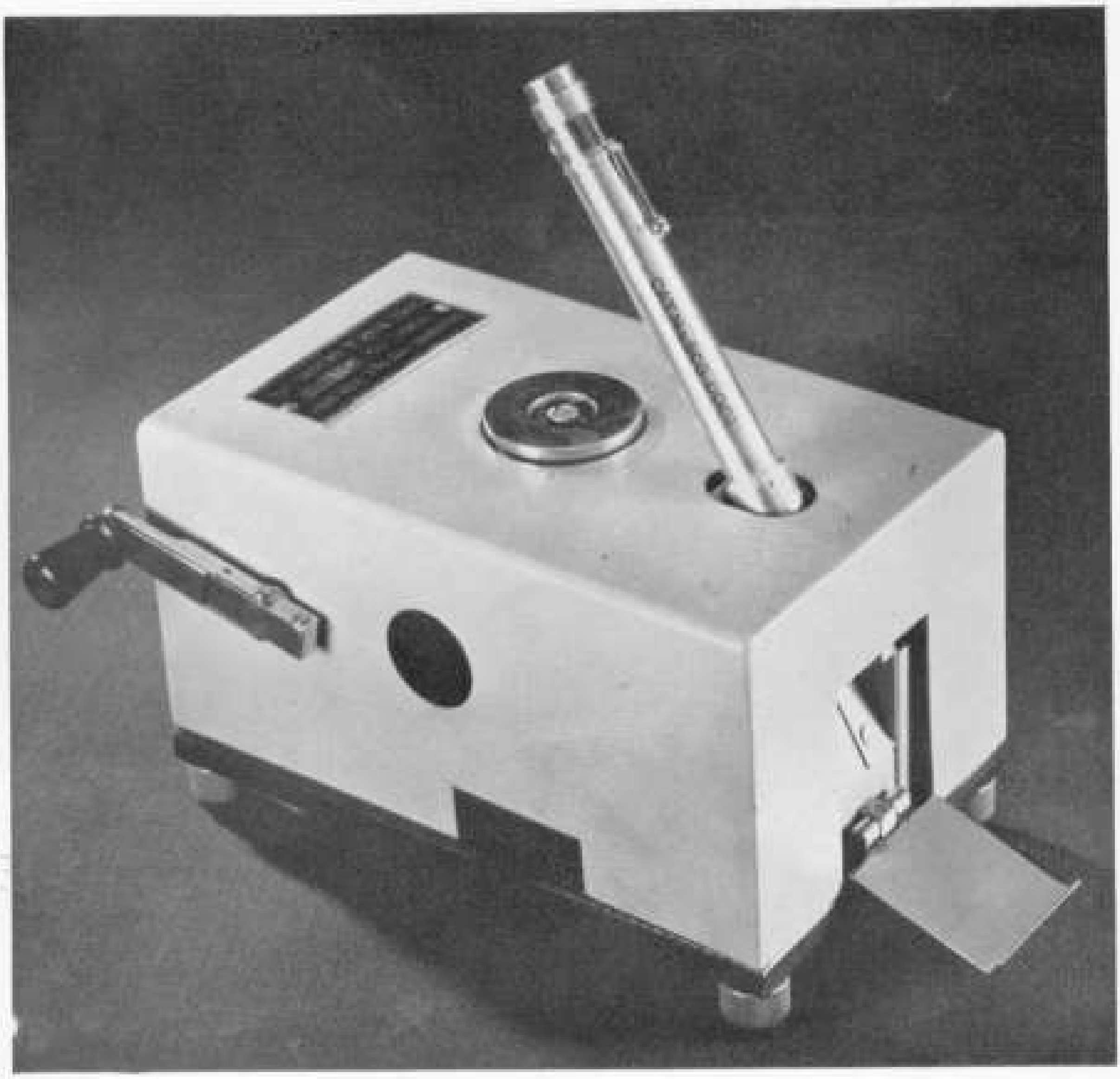

Plate 6
Charging unit for individual dosimeter

Plate 7.
Individual dosimeter in
transparent plastic sheath

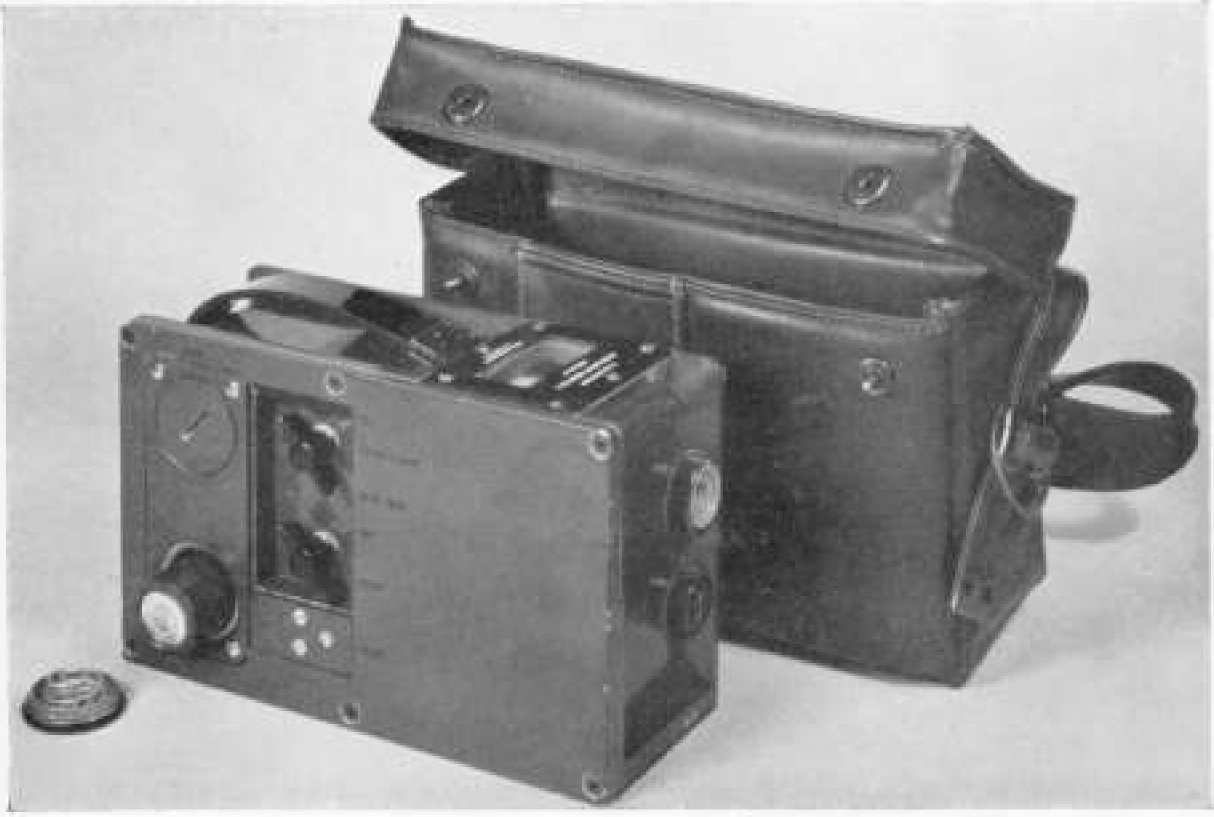

Plate 8
Radiac survey meter No. 2 (range selection switch)

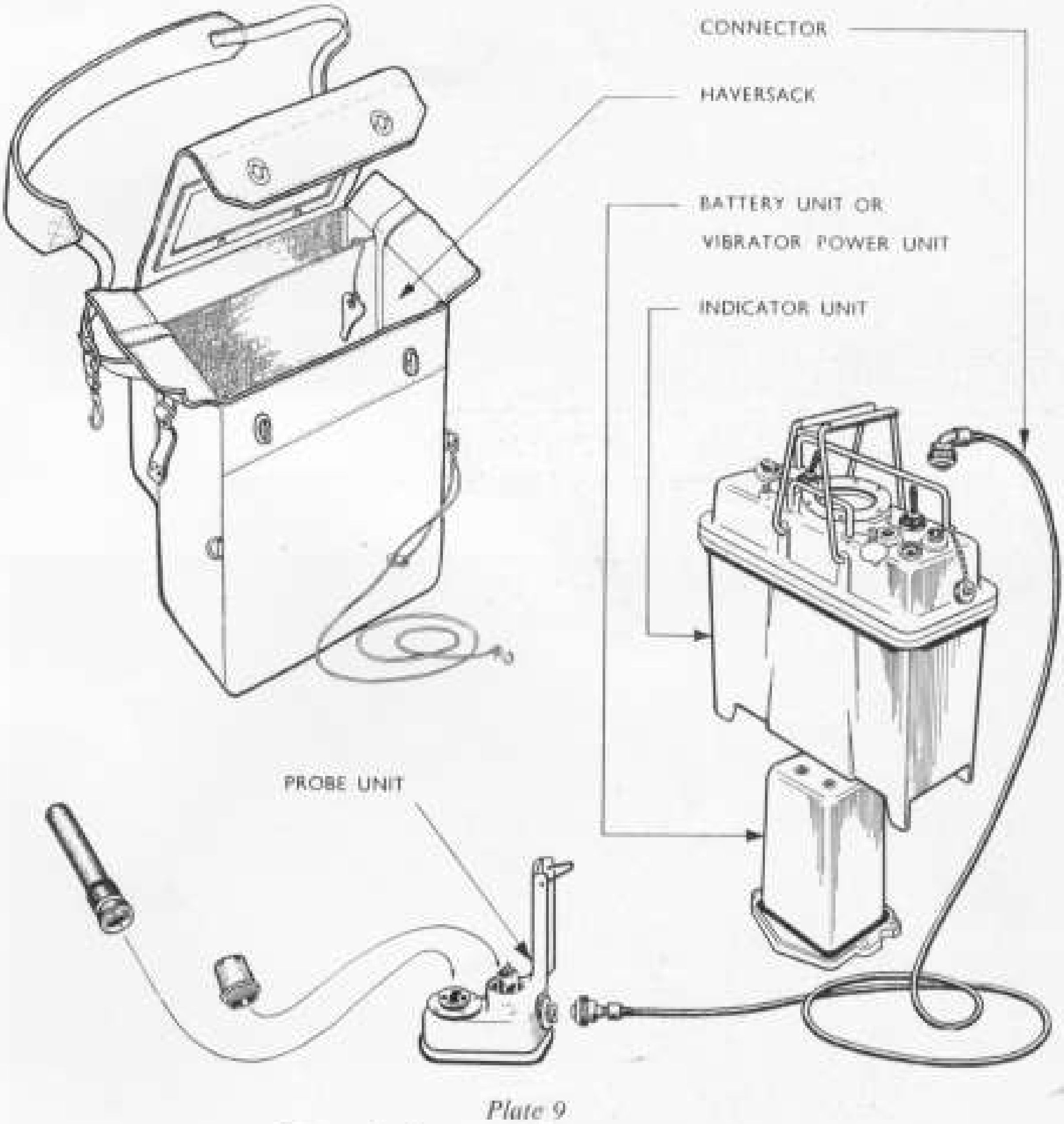

Plate 9
Contamination meter (Geiger counter probe)

Plate 10
Radiac survey meter No. 1 (single linear scale reading)

Plate 11
Brick house at just under one mile from ground zero before test explosion, Nevada, 1955

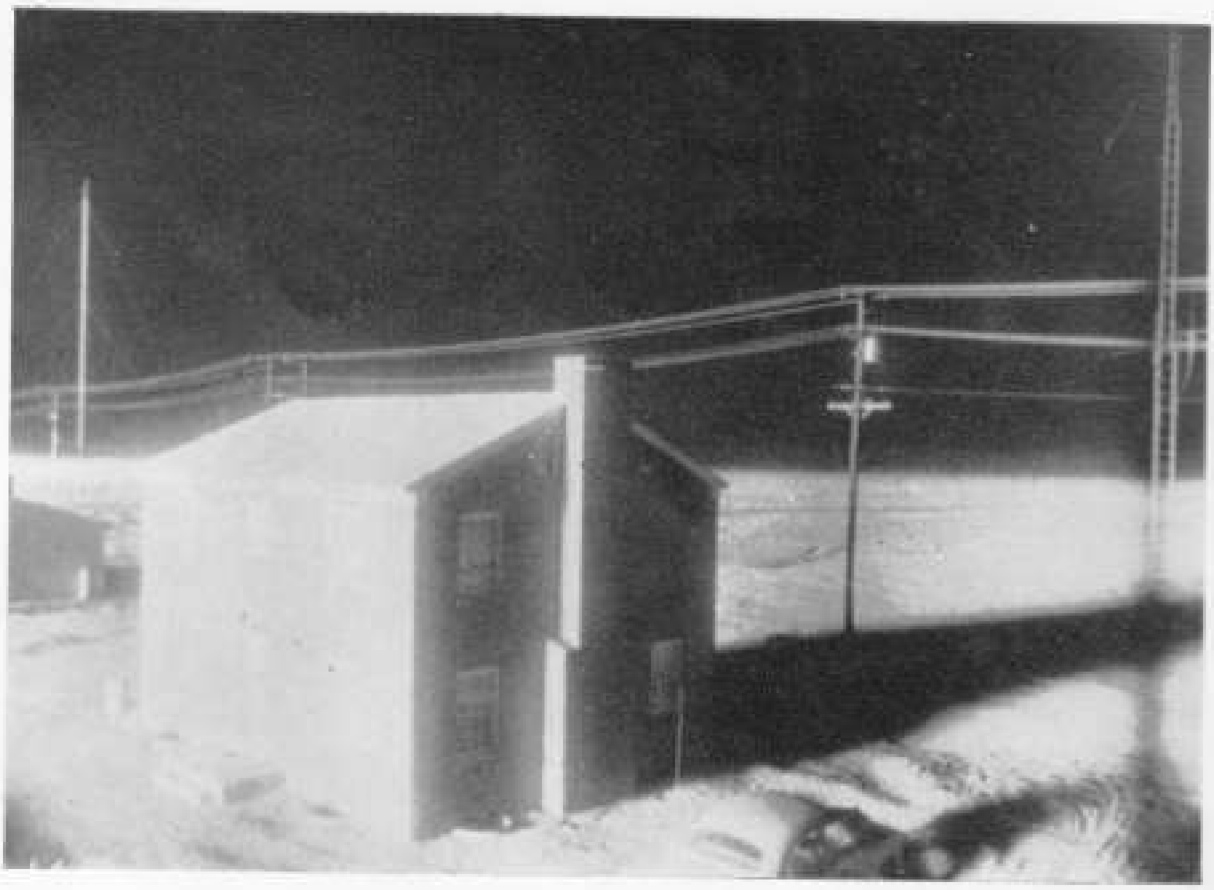

Plate 12
The same house at the moment of the explosion (sequence 1)

Plate 13
Heat effect striking the house (sequence 2)

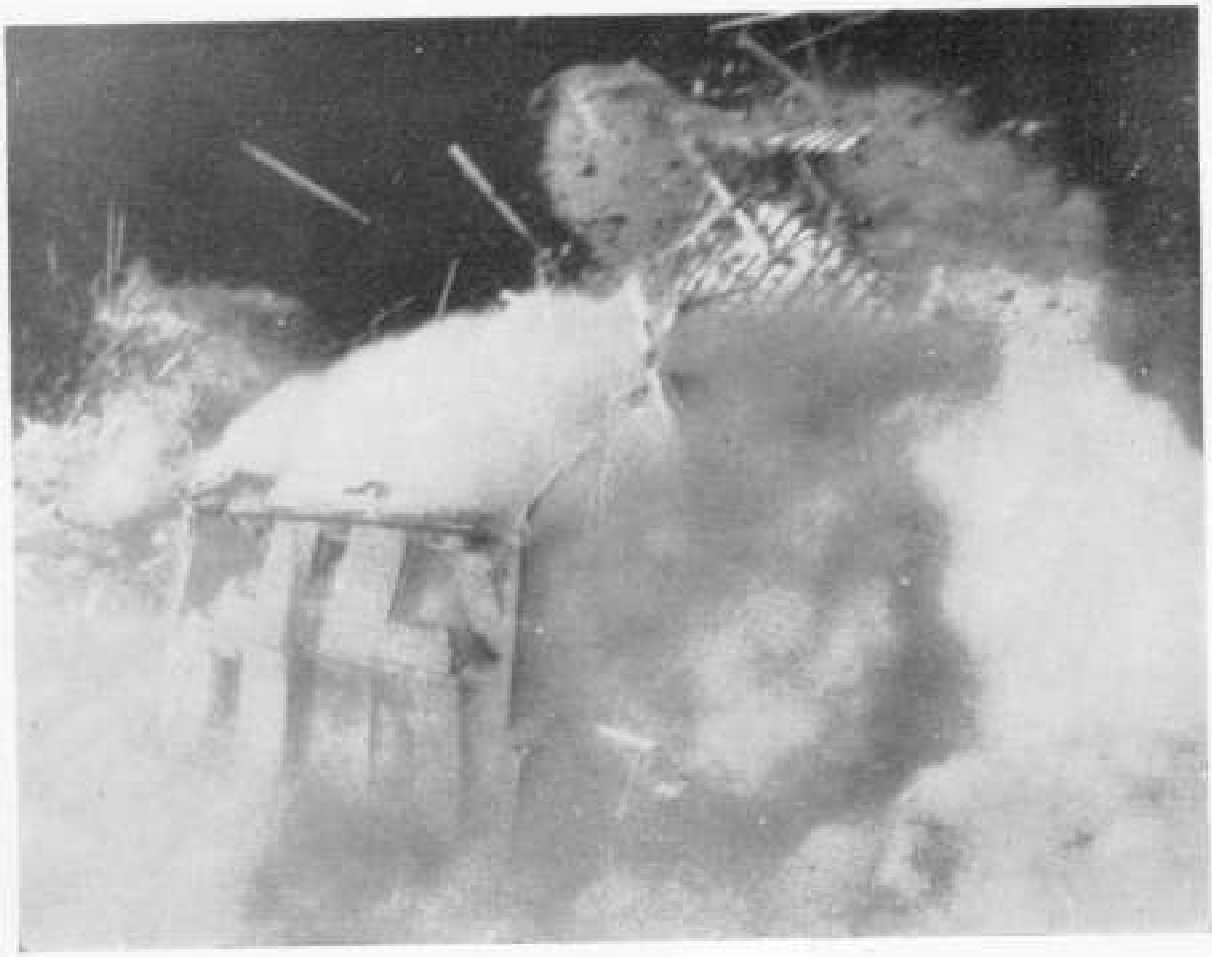

Plate 14
Blast striking the house, causing it to " explode " (sequence 3)

Plate 15
All that remained of the house (sequence 4)

over and around the building, the pressure on that face falls again rapidly to the normal peak pressure in the shock front (i.e. before reflection occurred) and this same pressure is exerted side-on to the building. The shock front then bends or "diffracts" round the opposite end until the whole building is engulfed in the blast wave and the same pressure is exerted on all four walls and on the roof.

7.7 Before the blast wave has completely surrounded the building there will be a considerable difference in the pressure on the sides facing towards and away from the explosion and, consequently, a force tending to move the building bodily in the same direction as the blast wave. If the building has relatively few openings (i.e. less than 5 per cent. of the surface area) it will be subjected to this lateral "diffraction" loading for the time it takes for the shock front to pass from one end of the building to the other. For example, if the shock front has to pass 75 ft. over a building, the diffraction load will operate for about a tenth of a second, but this could be long enough to cause considerable damage.

7.8 After the blast wave has engulfed a building with few openings, there may be insufficient time for air pressure equalisation (i.e. for the pressure inside to build up to the value outside) and the building will be subjected to the crushing effect of the higher external pressure on the roof and on all four walls; this crushing load will last as long as the positive pressure wave (several seconds in the case of megaton weapons at the limit for complete destruction).

7.9 In buildings with normal amounts of window openings, equalisation will occur fairly quickly and, because of reflections, the pressure inside may build up until it exceeds the external pressure. This may lead to the building exploding outwards since buildings are designed to stand external wind loads but not significant internal pressures. This explosion effect, which is common in hurricanes, has been observed in houses subjected to atomic blast in American trials and might well be the typical mode of failure of British houses at the limiting distances for total destruction (see Plates 11 to 15).

Wind drag loading

7.10 Wind drag forces act throughout the duration of the positive pressure wave which may last several seconds for megaton weapons. They affect mainly structures which, because of their small size, allow rapid equalisation of pressure round them but which are not vulnerable to an all-round external pressure. The most important examples are telegraph poles, trees and open girder bridges.

Relation between blast effects of air- and ground-burst weapons

7.11 As noted in paragraph 1.22, the range of blast damage is substantially greater for an air-burst than for a ground-burst weapon. The exact magnitude of the increase depends upon the category of blast damage under consideration (it is greater for the less severe categories) and upon the exact height of burst. However, for most practical purposes it can be assumed that the radii of the various categories of damage shown in Tables 11 to 14 for ground-burst bombs would be increased possibly by as much as 30 per cent. if the weapon were air-burst at about the optimum height.

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*
Damage ring " A " Houses totally destroyed, streets impassable . .	0–⅜	0–¾	0–1¼	0–1½	0–2	0–2¾	0–3½
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
Damage ring " C " Houses severely to moderately damaged : progress in streets made difficult by debris	⅝–1⅜	1–2¾	1¾–4¾	2¼–6	3–7½	3¾–10	5–13
Damage ring " D " Houses lightly damaged, streets open but some glass and tiles	1⅜–2½	2¾–4½	4¾–7½	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 abutment 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 blow 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	6½	8	10½	14

CHAPTER VIII

Effects of Residual Radiation from Fall-out

Introduction

8.1 The radioactive fission products from a nuclear weapon, burst on or near the ground, would condense on debris and dust lifted by the explosion and would be deposited around the crater or dropped from the cloud, more or less slowly, as it swept over a broad area which might extend several hundred miles downwind.

8.2 Particles of half a millimetre down to about one-fiftieth of a millimetre in size (i.e. from 500 down to about 20 microns*) would be deposited over a wide area in a complex pattern of radioactive fall-out, the shape and extent of which would be determined by the wind strengths and directions at the various levels through which these particles fall. With the average winds in the United Kingdom the fall-out pattern might extend to several hundred miles downwind of the point of burst (ground zero).

8.3 Particles less than one-fiftieth of a millimetre (20 microns) in size would be carried by the wind to much greater distances and might not be deposited on the ground for many days or weeks, or several years if they had been carried into the stratosphere. By that time the radioactivity would have decayed several thousand-fold and the individual particles would have become so widely dispersed in the atmosphere that in war-time they would no longer represent a significant fall-out hazard when finally deposited.

8.4 Residual radiations are those emitted later than one minute after the detonation of a nuclear weapon. They come from radioactive fission products mainly fused into or adhering to particles of dust and debris lifted by the explosion and, if it is not too high an air burst, from radioactivity induced in these particles and in the ground by neutrons escaping from the detonation. The induced activity would effectively decay within a few days whereas the fission products would decay at a decreasing rate, corresponding to the $R_1t^{-1 \cdot 2}$ formula over a long period as mentioned in paragraph 3.2 and footnote.

The different hazards presented by fall-out

8.5 There are many ways in which large fissile atoms can split into two not quite equal parts, and consequently fission products consist of some 200 different types of atomic nuclei or isotopes of about 35 elements.

8.6 These radioactive isotopes are unstable and tend to disintegrate or decay in one or more stages. In doing so they get rid of excess energy by emitting one or more of the following:—

(*a*) *Alpha particles* which are four times as heavy as hydrogen atoms and lose all their energy by collision with other atoms

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* A micron is one millionth of a metre (thousandth of a millimetre).

in passing through a few inches of air; they cannot penetrate clothing or unbroken skin.

(*b*) *Beta particles* which are high-speed electrons or negative charges of electricity stopped by air within 2 to 12 yds. depending on the energy with which they are expelled from a nucleus: they are unable to penetrate deeply beneath clothing and skin but they may cause skin burns.

(*c*) *Gamma rays* which are forms of electromagnetic radiation like light and heat and which travel with the speed of light: in air they can reach distances of many hundreds or even thousands of feet before they are stopped by the atoms of oxygen and nitrogen in the atmosphere; like X-rays they can penetrate, but more readily, through the deeper tissues and organs of the body.

8.7 It should now be clear that radioactive fall-out presents two separate and distinct hazards:—

(*a*) *Contact* with, or close proximity to, the skin or organs within the body, e.g. fall-out on light clothing, on the skin and hair, or inside the body by access through cuts or in food or water.

(*b*) *Gamma radiation* or rays which can shine from a distance on to the whole body from fall-out deposited over a wide area: these rays are also scattered back from the atmosphere like light scattered back from a mist or cloud.

8.8 Different methods are employed to measure these two types of hazard. The contact hazard is measured with an instrument which counts the number of atoms disintegrating each second on a limited area of a surface very close to the instrument. The radiation hazard is measured as the dose-rate or intensity of radiation reaching the instrument when it is held at a specific height (usually 3 ft.) above a large contaminated surface (see Chapter III on instruments).

Detection and warning of fall-out

8.9 Under some circumstances it is possible that fall-out particles might be seen coming down or they might be visible as dust on some surfaces. But, in general, it must be assumed that fall-out might not be noticed and, since the human senses are incapable of detecting nuclear radiations, special instruments are required for this purpose (see Chapter III). Hence, it would be imperative, if a warning* of imminent fall-out had been given, for everyone in that area to seek the best and heaviest possible all-round cover from gamma radiation, preferably in a prepared refuge containing food, water and emergency sanitation (if there were no normal indoor sanitary facilities) sufficient for at least two days and preferably for seven days. It would be necessary to remain under cover until the intensity of the gamma radiation in the area could be monitored and until it had decayed sufficiently to permit outdoor exposure, or in the worst case, until arrangements could be made for the rapid clearance of people from that area.

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* See paragraphs 3.4 and 3.5. A provisional warning code is given on page 9 of Pamphlet No. 2 (Radioactive Fall-out—Provisional Scheme of Public Control) in the Manual of Civil Defence, Vol. I. This pamphlet is published by H.M. Stationery Office, price 1s. 3d. net.

Relation between distance from nearest fall-out and total dose

8.10 Figure 4 shows a man standing on ground evenly contaminated with fall-out and the fraction of the total radiation dose which he would receive from various distances. It will be observed that half of the total dose would come from within a circle roughly of radius 25 ft. around him. (This radius would be greater on a very smooth ground and less on rough and uneven ground.)

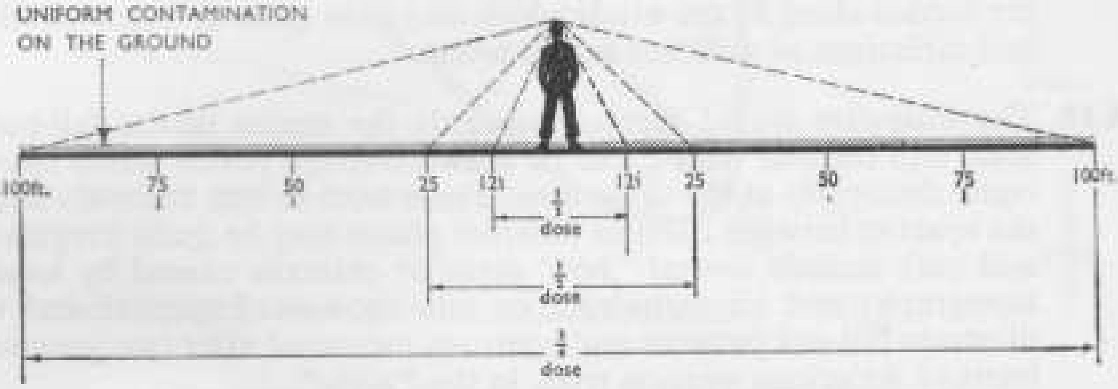

FIGURE 4

Total dose from fall-out—contribution from different distances

Relation between the external radiation hazard and the hazard from breathing or swallowing fall-out particles

8.11 When fall-out is coming down, or in an area already covered by radioactive fall-out, the gamma radiation hazard from the surroundings would be far greater than the hazard from any radioactive dust which might be inhaled or swallowed. The first necessity would be to get protection from the general field of gamma radiation—get inside a building as far below the roof as possible and behind the thickest available walls (see paragraph 1.31).

8.12 Nevertheless, every effort would have to be made to avoid getting radioactive fall-out on the skin, hair and clothing and if this proved impossible, steps should be taken to remove it as soon as this was practicable. Some very active isotopes of strontium and iodine may present a special hazard of internal injury developing years later. The first of these isotopes accumulates to some extent in the growing parts of the skeleton: even a minute quantity irradiating the bone over many years may ultimately injure the blood regeneration system which takes place in the bone marrow. Radio-iodine accumulates in the thyroid gland and although it decays in a few weeks (half of it has gone by 8 days) it can be particularly injurious in the very small thyroid gland of an infant (see also paragraph 10.4).

8.13 Ordinary headgear, clothing, boots and gloves can keep fall-out and the alpha and beta particles away from the body and give temporary protection against the contact hazard, but they should be removed and decontaminated or replaced at the earliest opportunity (see paragraphs 11.23 to 11.25). *They do not provide any significant protection against gamma radiation.* Personal cleanliness is essential to remove radioactive fall-out from the clothing or skin and to prevent its entry into the body.

Fall-out patterns and dose-rate contours

8.14 If the boundary of the fall-out area is determined with radiac survey meters (paragraph 3.17) and plotted on a map, it would probably have an irregular shape in usual British weather conditions. There are two main reasons. The first is that particles of different sizes fall at different rates from all parts of the very extensive cloud, e.g. a particle one millimetre in diameter falls from 60,000 ft. in about a quarter of an hour compared with about 20 hours for a particle 20 times smaller. The second reason is that, as the particles fall, they are carried along by the winds which may have quite different speeds and directions at different height levels.

8.15 The dose-rate would increase towards the centre of the fall-out area, and contour lines could be drawn through points which have equal dose-rates at the same time. These isodose-rate contours and the spacing between them at different places may be quite irregular and may include several "hot" areas or plateaus caused by local topography and air turbulence or rain showers. Figures 5 and 6 illustrate fall-out patterns and contours measured after two ground burst at American weapon trials in the Pacific*.

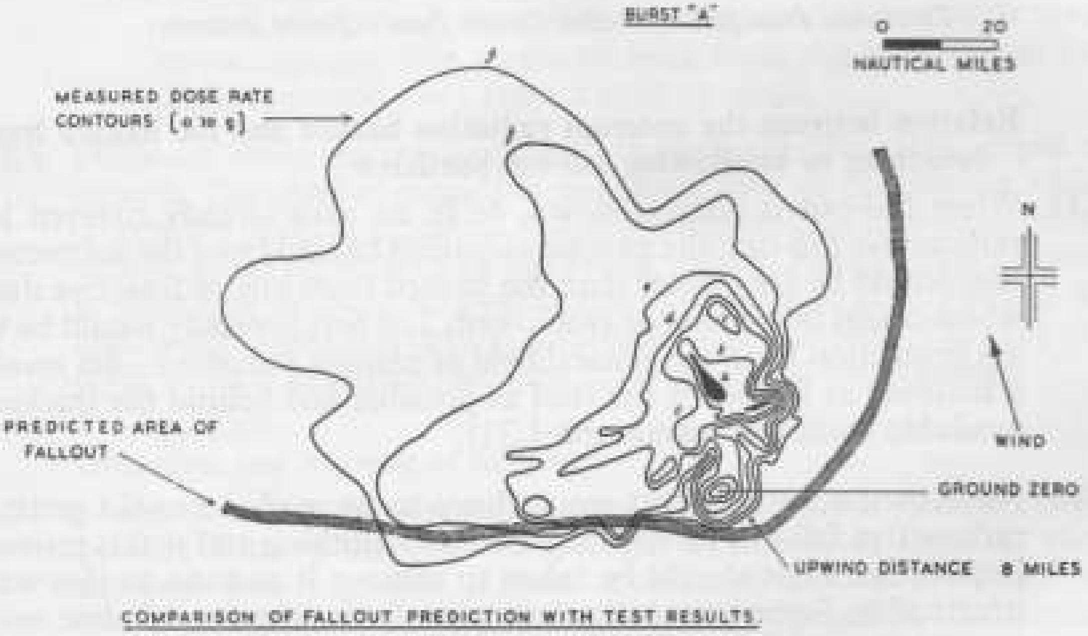

FIGURE 5

Comparison of fall-out prediction with test results : Burst " A "

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* The detonations were reported to be in the megaton range but no values were assigned to the individual contours. These figures were taken from the U.S. Congress Publication, " The nature of radioactive fall-out and its effects on man " (Hearings before the Special Sub-Committee on Radiation, 27th May to 3rd June, 1957) Part I, pages 304 and 305.

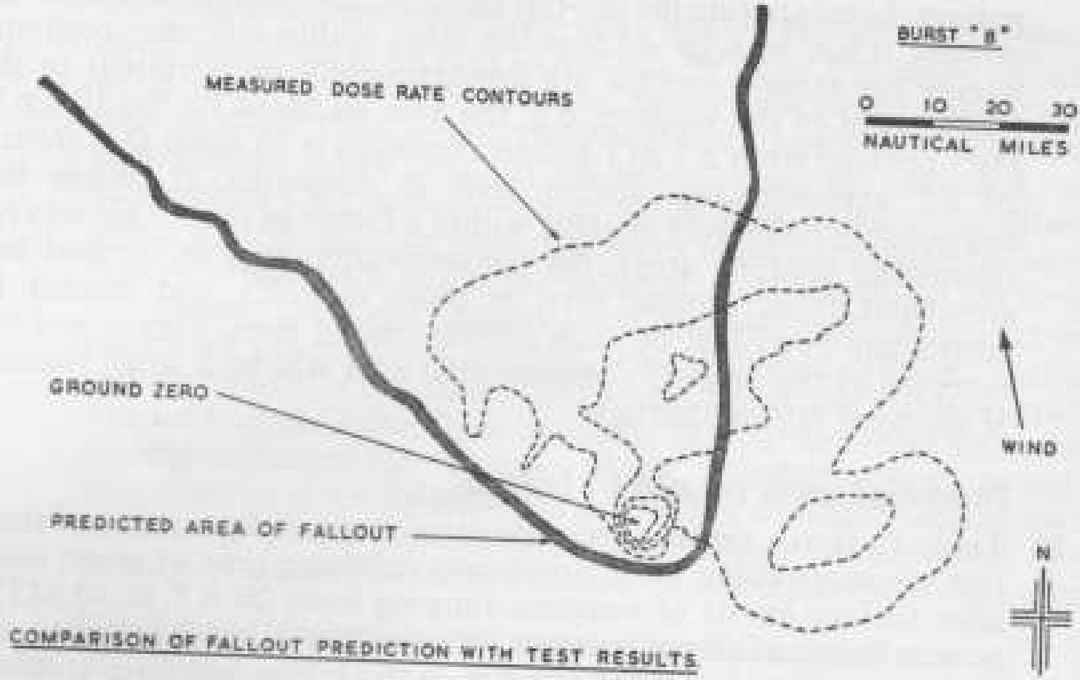

FIGURE 6

Comparison of fall-out prediction with test results : Burst " B "

8.16 Since fission products decay rapidly at first and then at a progressively decreasing rate represented by formulae such as the $t^{-1.2}$ decay law or the seven-tenths rule (see paragraph 3.3), the fall-out pattern on the ground would be contracting as it formed. Early fall-out close to the damaged area might be all down in one or two hours after the detonation whereas 200 miles downwind, assuming a mean wind of 20 miles per hour, it would not start for another 8 hours and it might continue for a further 10 to 15 hours, by which time it would have decayed by a factor of between 20 and 30 compared with the earlier fall-out.

Standard reference time for dose-rate contours

8.17 It is clear that a standard reference time is needed to define a consistent set of fall-out contours and to enable the dose-rates at any place within the pattern to be calculated at any other desired time. For civil defence purposes it is convenient to choose as the standard reference time either one hour (H+1) or seven hours (H+7) after the detonation (the seven-hour contours are preferable). In practice, dose-rates would be measured and reported together with the times and positions as soon as the maximum readings had been reached. From the decay law these dose-rates could then be converted to the dose-rates corresponding to the standard reference time. In this way, a pattern of one-hour (DR1) or seven-hour (DR7) reference dose-rate contours could be built up on a map as the fall-out front advanced over the country; from this pattern, it would be possible to calculate what the dose-rates would be at any required place and time after the fall-out had come down. Civil defence operations could then be planned in the light of this information.

Relation between bomb power and contour areas

8.18 Aerial and ground surveys of the fall-out at weapon trials have shown that about two-thirds of the total fission product activity from a surface burst is deposited in a day or two within the fall-out 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

30 r.p.m. seven-hour reference contour (DR7) from a 1 MT ground burst would cover an area of 650 square miles and might extend 80 miles downwind. At the extreme downwind edge of this contour fall-out might start to come down about 4 hours after the detonation. People at this point, if unshielded from the radiation, could accumulate a dangerous dose of about 360r by 48 hours after the burst. In some districts (covering only a small proportion of the total area of 650 square miles) the external dose-rate might be so high that people could not remain, even in a prepared refuge, for more than a few days without suffering from radiation sickness. Throughout the whole of the downwind fall-out area the public would be warned to seek shelter from imminent fall-out and from the residual gamma radiation (see paragraph 8.9). Further advice* would be broadcast or given by whatever means are available locally, on the subsequent permissible daily periods of outdoor exposure to get essential food and medical supplies or to perform essential duties.

Upwind and crosswind contamination in the damaged area

8.22 The urgent tasks of fire-fighting and rescue in the damaged area would raise two major questions. Would it be worthwhile to commit fire-fighting and rescue forces early, knowing that subsequent fall-out would compel them to seek refuge and become immobilised? How far would fall-out extend into the upwind damaged area and to what extent would high dose-rates prevent access by fire-fighting and rescue forces?

8.23 Unfortunately, the information available would not always provide clear-cut answers to these questions and existing information is not so well supported by experimental measurement as that on the downwind pattern and contours. For training and instruction purposes, two examples are given in Table 16 representing possible degrees of contamination in the damaged upwind area.

Cloud models consistent with actual fall-out patterns

8.24 Samples of radioactive particles collected by rockets and aircraft from known points within the stabilised clouds have enabled the following conceptual cloud models to be evolved:—

(i) For weapons of less than 100 KT the cloud appears to be roughly spherical with a uniform distribution of radioactive particles: the dimensions of the cloud can be estimated in relation to the power of the weapon from Table 24 in Appendix 2.

(ii) For weapons of 100 KT and higher powers, the cloud can be visualised as a flat disc of approximately 25,000 ft. thickness (irrespective of weapon power) on top of the stem: hence, the diameter of the disc increases in proportion to the square root of the weapon power (see scaling laws, Appendix 2). Nearly all the activity is concentrated in the upper third of the stem and in the central and lower third section of the cloud disc.

8.25 The largest particles (about 1,000 microns† in size) are concentrated at the top of the stem. These particles take about one-quarter of an hour to fall from 60,000 ft. which is approximately the mean height

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* Manual of Civil Defence, Vol. I, Pamphlet No. 2 (Radioactive Fall-out—Provisional Scheme of Public Control), published by H.M. Stationery Office, price 1s. 3d. net.

† 1 micron is one millionth of a metre.

of the stabilised cloud disc from a 1 MT detonation. Particles of 500 microns in size are found out to about half the radius of the cloud (fall-time nearly 1 hour from 60,000 ft.), while the maximum size of the particles at the extreme edge of the cloud disc is presumed not to exceed 250 microns (fall-time about 3 hours from 60,000 ft.). To the above fall-times must also be added the time taken by the cloud to reach its maximum altitude and become stable. This is about 7 minutes for a 1 MT detonation.

8.26 In the absence of wind at any level up to cloud height (a very rare occurrence in the U.K.) the cloud models predict a circular fall-out pattern around ground zero with the same radius as the cloud, i.e. 30 miles for a 10 MT detonation (see scaling laws, Appendix 2, paragraph 4). With a 15 mile per hour wind in the same direction at all relevant height levels, the 500 micron particles in the cloud from a 10 MT bomb would extend out to 15 miles from the cloud centre and would take about 1 hour to be deposited on the ground in the neighbourhood of ground zero. A 250-micron particle falling from the extreme upwind edge of the cloud for 3 hours would be deposited on the ground 45 - 30=15 miles *downwind* of ground zero and smaller particles would fall still farther downwind.

8.27 The cloud model for the larger weapons indicates that very little fall-out is likely to be deposited upwind beyond the limit of complete destruction, unless the winds at all levels up to cloud heights are of exceptionally low speed or are in opposite directions at different heights. Around the upwind half of the damaged area the extent and intensity of radioactive fall-out will depend upon weather conditions at the time. The situation may vary from complete prevention of fire-fighting and rescue to complete freedom from fall-out in the damaged area beyond the range of complete destruction. For exercise purposes Table 16 has been included showing upwind distances to a series of *1-hour reference contours* for two possible patterns of fall-out from a large megaton weapon (under low and moderate wind conditions).

TABLE 16
Contamination upwind in the damaged area (10 MT)
Upwind distances from G.Z. to 1-hour reference contours (DR1's) for two possible contamination patterns

Dose-rate at 1 hour after burst (DR1) r.p.h.	*Upwind distance (miles) for mean winds of*	
	5 m.p.h.	*15 m.p.h.*
0.3	21	7
1.0	16	5
3	11	4
10	7	2
30	4	in crater
100	2	"
300	in crater	"

8.28 Crosswind from ground zero, on the flanks of the damaged and contaminated area, the contour for any given dose-rate will extend farther than it will directly upwind, so that restrictions on fire-fighting and life-saving will be more severe on these flanks. For exercise purposes it can be assumed that in estimating crosswind distances the corresponding upwind distances in Table 16 should be increased by about 25 per cent. for dose-rates up to 10 r.p.h. at 1 hour, by 50 per cent. for dose-rates from 10 to 100 r.p.h. at 1 hour, and doubled for higher intensity contours.

8.29 *In the damaged area, directly downwind of ground zero, civil defence operations will be prevented or severely restricted under all wind conditions.*

CHAPTER IX

Protection afforded by Buildings, Trenches and Vehicles against Gamma Radiation from Fall-out

Introduction

9.1 This chapter describes a method which has been devised for assessing the protection afforded by dwelling houses and other buildings against gamma radiation from fall-out based on the dimensions of the building and the weight of the material used in its construction. It omits allowances for a number of factors such as the shielding effect of neighbouring buildings, the shape of the building when its length is more than twice its breadth and the proportion of wall area consisting of openings such as partially blocked windows and doors. In spite of these omissions it enables a rough estimate to be made of the protection obtainable in certain types of dwelling house which are common in the United Kingdom and do not give the high degree of protection afforded by more substantial large buildings such as office blocks, flats and tenements.

9.2 Gamma radiation can penetrate all material but the intensity of radiation passing through any material is progressively reduced, and if the material is of adequate thickness it affords protection of practical value. The protection afforded increases with the weight of material between the source or sources and the persons to be protected, e.g. 9 in. of brickwork (equivalent to 7 in. concrete) will reduce the dose-rate to about one-tenth of what it was.

9.3 The gamma dose-rate which a person receives depends also on his distance from the source of radiation and it is inversely proportional to the square of the distance, e.g. doubling the distance gives a fourfold reduction in dose-rate.

9.4 From the above it is clear that a building affords protection in two ways according to its size and the position of the occupants inside. Firstly, it keeps the radioactive fall-out at a distance and reduces the dose-rate in inverse proportion to the square of this distance and, secondly, the weight of the walls, upper floors and roof themselves reduce the dose-rate.

9.5 Large massive buildings therefore afford a very high degree of protection and some shielding is additionally afforded by any other surrounding buildings.

9.6 The distribution of radioactive fall-out matter around a building cannot be accurately predicted and buildings differ so widely in dimensions and type of construction that it is not easy to take into account all the variations in the shape and massiveness of the walls. Some approximations and assumptions must therefore be made in devising a simplified method of calculation which will be applicable to any building.

Protective factors of buildings and houses

9.7 The protection afforded by a building against the gamma radiation from fall-out is usually, and most conveniently, expressed as the "protective factor"* (PF) of the building; that is the factor by which the dose-rate received by a person in the building is reduced as compared with that received by a person standing in the open, or more accurately, on an infinite flat plane. Thus, if a particular building has a protective factor of 100 it means that the dose-rate for a person in the building is 1/100th of the dose-rate he would be receiving in the open.

9.8 In calculating protective factors it is assumed:—

- (*a*) that the radioactive material is uniformly deposited on the ground and on the roof, that the roof is flat with the same overall length and breadth as the external walls of the building, and that the height of the building is the average height of the actual roof between the eaves and the ridge;
- (*b*) that there is no deposit on the walls, window-sills or any projections from the walls;
- (*c*) that no radioactive material enters the building.

9.9 Even in a simple rectangular building the protective factor will vary considerably from place to place in the building; it will be greatest at positions shielded by upper floors or internal walls and least near windows, doors or thinner parts of the external wall. Allowance cannot easily be made for this variation and, in general, the protective factor at 2 ft. above the mid-point of the floor level of the building is calculated and taken to hold for the whole of that floor level. Many buildings are not of simple rectangular shape, but it is not feasible to take into account relatively minor deviations; where irregularities exist in the form of annexes and so on, the average length and breadth of the whole should be taken for use in the calculations. The method of dealing with parts of buildings which are sub-divided by internal walls or partitions is dealt with in paragraph 9.19 and 9.20.

9.10 The degree of protection afforded is determined by the thickness and density of the materials of which the walls, floor and roof are constructed and these factors are most conveniently combined as weight per square foot of wall, floor, or roof area.

9.11 In practice, the walls and floors of a building are seldom of uniform thickness throughout, walls are thickened in places by buttresses and chimney breasts and floors by beams. Variations of this sort are averaged, for example, in the case of a beam and slab floor, the total weight of the beams and slabs comprising it is divided by the area of the floor. Precise weights of wall, floor and roof material may be difficult to obtain but a structural engineer familiar with building construction should be able to estimate the weights per square foot of wall or floor area with an accuracy which is adequate for the purpose of this calculation. Weights per square foot area and per inch thickness of some common building materials are given in Table 17.

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* This has also been descibed as the " attentuation factor " (AF).

TABLE 17

Weights of some common building materials

Brickwork	per in. thickness	10	lb. per sq. ft.
Stone	,, ,, ,,	12	,, ,, ,, ,,
Reinforced concrete	,, ,, ,,	12	,, ,, ,, ,,
Asphalt	,, ,, ,,	12	,, ,, ,, ,,
Hollow tile	,, ,, ,,	8	,, ,, ,, ,,
Plaster	,, ,, ,,	8	,, ,, ,, ,,
Boards	,, ,, ,,	4	,, ,, ,, ,,
Tiles		14–18	,, ,, ,, ,,
Slates		8	,, ,, ,, ,,
Corrugated asbestos cement sheets		3½	,, ,, ,, ,,
Corrugated steel sheets		2–3	,, ,, ,, ,,

9.12 In preparing a refuge room it would be desirable to block up openings direct from the refuge to the outside, e.g. windows and external doors. Protective factors should be calculated on the assumption that this has been done and that, to get the same advantage, the blocking material has the same weight in lb. per square foot as the wall area.

Shielding against residual gamma radiation: half value thicknesses of shielding materials

9.13 The thickness of shielding material needed to reduce the dose-rate in a beam of gamma rays by half is called the half value thickness of that particular material. This is illustrated in Figure 7 for residual gamma radiation: each successive "half value" layer reduces the dose transmitted by half. (See also paragraph 4.10.)

9.14 Table 18 shows the half value thickness for common materials of construction against residual radiation from fall-out.

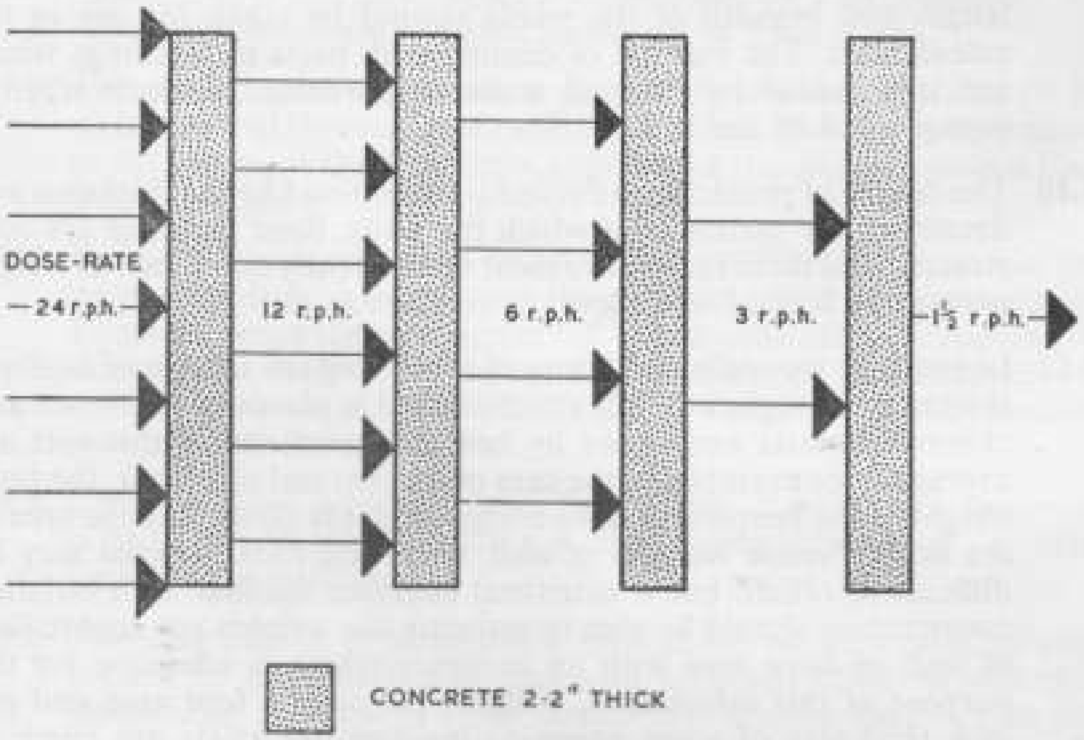

FIGURE 7

Diagrammatic illustration of the reduction of residual gamma radiation intensity by successive 2.2 in. half value layers of concrete or equivalent shielding material.

TABLE 18

Half value thicknesses of shielding materials against residual radiation

Material	*Slab density lb. per square foot and per inch thickness*	*Half value thickness (inches)*
Steel	41	0.7
Concrete	12	2.2
Brickwork	10	2.8
Earth	8	3.3

Thus a 2·2 in. thickness of concrete will reduce the dose of residual radiation to one-half of its original value, 4·4 in. will reduce it to a quarter, 6·6 in. to one-eighth and so on. Brick walls 4½, 9 and 13½ in. thick will reduce the intensity of residual radiation by factors of 3, 10 and 30 respectively. As shields are made thicker and larger the contribution from scattered radiation which penetrates increases, so that the reduction factor is slightly more for thinner shields and slightly less for thicker shields than those indicated above.

Method of calculating protective factors

9.15 External radiation can be regarded as entering the building from five directions, namely, through the roof and through each of the four walls: this is equivalent to five separate sources each of which contributes, by addition, to the total radiation intensity inside. Each of these separate contributions can be conveniently expressed as a percentage of what the intensity outside would be at 2 ft. above an infinite plane. Tables 19 and 20 enable the contributions to this total percentage to be calculated for the roof and for each wall. These contributions are added to give the total percentage: 100 divided by this total is taken to be the protective factor for the building.

TABLE 19

Percentages of gamma radiation penetrating through the roofs of buildings of various dimensions

Weight of overhead material in lb. per square foot of floor area	*Percentage of radiation penetrating roof for values of* $\frac{L+B}{H-2}$ *where L=length, B=breadth and H=height to average roof level, all in feet*					
	1	*2*	*3*	*4*	*5*	*6*
10	0.6	2.2	4.7	7.1	9.4	11.8
20	0.5	1.9	4.0	6.2	8.2	10.3
30	0.4	1.5	3.2	5.0	6.6	8.4
40	0.3	1.1	2.4	3.9	5.1	6.5
50	0.3	0.9	2.0	3.2	4.1	5.2
60	0.2	0.7	1.6	2.4	3.2	4.0
70	0.2	0.6	1.3	2.0	2.6	3.2
80	0.1	0.5	1.0	1.5	2.00	2.5
100	0.1	0.3	0.6	0.9	1.3	1.6

TABLE 20

Percentages of gamma radiation penetrating through walls of buildings

Weight in lb. per square foot of wall area	*Percentage of radiation penetrating the wall for distances from external wall of :*					
	5 ft.	*10 ft.*	*15 ft.*	*20 ft.*	*25 ft.*	*30 ft.*
20	16.0	14.0	12.7	11.4	10.5	10.0
40	9.9	8.8	8.0	7.3	6.8	6.3
60	6.3	5.4	4.9	4.4	4.2	3.9
80	3.9	3.4	3.0	2.8	2.6	2.4
100	2.5	2.2	1.9	1.8	1.6	1.5
120	1.5	1.3	1.2	1.1	1.0	0.9
140	0.9	0.8	0.7	0.6	0.6	0.6
160	0.6	0.5	0.5	0.4	0.4	0.4

Example

9.16 *Roof.* To find the roof contribution the first step is to calculate the value of $\frac{L+B}{H-2}$.

The next step is to estimate the weight* of the overhead material (roof and upper floors in lb. per square foot of floor area). The approximate roof contribution may then be read from Table 19. Thus, if L=40, B=20 and H=25 we have $\frac{L+B}{H-2}=2 \cdot 6$. If the weight of overhead material is 40 lb./sq. ft. we find from Table 19 that the approximate roof contribution is 1·9 per cent.

Walls. The contribution through each wall can be found immediately from Table 20 when the distance from the mid-point of the floor to the outer side of the wall at ground level and the weight of material per square foot of wall are known. For example, if the mid-point of the building is 20 ft. from a wall of 100 lb./sq. ft. the wall contribution is about 1·8 per cent. For floors above ground level the slant distance, from 2 ft. above the mid-point of the floor to the foot of the wall outside at ground level, should be used.

9.17 In basements the wall contributions decrease uniformly and rapidly with depth below ground level down to about 7 ft. where they are assumed to be zero. Thus, if a wall contribution at ground floor level is 3·5 per cent., the contribution at 2 ft. below ground level should be taken as $3 \cdot 5-\frac{2}{7}\times 3 \cdot 5=2 \cdot 5$ per cent.

9.18 If the roof contribution amounts to 1·9 per cent. and the percentage contributions through the four walls are 1·8, 1·8, 0·6 and 0·0† respectively, then the total percentage of the external radiation which penetrates the building is 6·1 per cent. and the protective factor is therefore $\frac{100}{6 \cdot 1}=16$ (approx.). In built-up areas the shielding effect of neighbouring houses would roughly double the protective factor calculated by this simple method.

Buildings sub-divided by internal walls

9.19 Many buildings have substantial internal walls and some of the rooms could provide good refuge against gamma radiation. Terraced houses and office blocks are examples of this kind of sub-division. Such rooms can afford very high protection if there is a large mass of material between the occupants and the radioactive deposits outside the building. Furthermore, the percentage contribution of radiation from fall-out on the roof will be smaller if the internal walls extend up to the roof, since the intensity of the radiation coming from those parts of the roof not directly above the selected refuge room will be again reduced by passage through the internal walls.

9.20 When the internal walls extend up to the roof and have a weight of 90 lb./sq. ft. or more, the following modification of the procedure in paragraph 9.16 should be used in calculating the protective factor for any selected refuge room in the building.

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* The weight of floor materials should comprise the weight of the floor itself together with the weight of permanent furniture, fittings and partition walls resting on the floors. This additional material is regarded as making an addition to the floor weight spread uniformly over the floor.

† Zero because it is shielded by adjacent parts of the building.

Roof. The percentage contribution of radiation through the roof should be determined from Table 19 but taking for the dimensions of the roof the distances between the internal walls.

Walls. The percentage contribution of radiation penetrating through the walls should be determined from Table 20 using distances measured from the mid-point of the room to the outer walls of the building at ground level: since the radiation now has to penetrate both external and internal walls the weight per square foot of wall material should be taken as the sum of the values for the external and the internal walls.

Survey of dwelling houses in the United Kingdom

9.21 Surveys have been made of different types of dwelling houses in the United Kingdom and their protective factors have been calculated for ground floor refuge rooms in which there is no external door and the windows have been blocked. For this purpose it was assumed that the fall-out is uniformly distributed on the roof and on the ground around the building. The calculated protective factors (which are approximate) are shown in Table 21.

TABLE 21

Approximate protective factors in ground floor refuge rooms of typical British houses with timber upper floors

Types of house	*Protective factor*
Prefab	3
Bungalow	5–10
Detached two-storey	15
Semi-detached two-storey 11 in. cavity walls	25–30
Semi-detached two storey 13½ in. brick walls	40
Terraced two-storey	45
Terraced back to back	60
Tenements	*

There is some evidence that the fall-out may not all remain on sloping roofs and that consequently the protective factors of most British houses will be higher than the values given in Table 21: this applies especially to the houses with the lower protective factors where a large fraction of the radiation comes from contamination on the low roof.

Basements and trenches

9.22 A substantial increase in protection could be obtained if any of the above houses had an additional cellar or basement, or a trench under the floor: e.g. for a two-storey house the trench would give a protec-

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* See paragraph 9.1. Protective factors in tenements can vary widely as they depend upon the size of the building, the massiveness of its construction and the number of storeys used as refuges. On the ground and first floors, PF's may vary from 100 to 500, on second floors the PF may be 50 and on top floors they may be in the neighbourhood of 20.

tive factor (PF) of about 200 and the basement a PF of between 140 and 340, depending on whether or not the basement was adjacent to a semi-sunk area, and if so, on the size of the latter.

9.23 A slit trench with even a light cover of wooden boards or corrugated iron and a tarpaulin will give a protective factor of 5 to 10 and with an additional 3 ft. of earth cover the protective factor will be very high (e.g. 200 to 300 or more).

Protection afforded by vehicles

9.24 The protective factors of various types of motor transport vary from about 1·5 upwards depending upon the size and weight of the vehicle, the height of the seating above the ground and on the number of passengers (who would shield one another to some extent). Since the abdominal part of the body is more sensitive than other parts to radiation, it may be possible for essential purposes to provide additional protection by means of a thick slab of metal or concrete as a seat and three vertical slabs round the hips but this would involve a severe weight penalty on the vehicle. Since fall-out would sink to a great extent in water, river and sea transport provide considerable protection. In passenger rail coaches the protective factor would depend on the amount of fall-out on the roof: with a clean roof and the coach on flat territory the PF should be about 5, but if the roof is contaminated a PF of 2 to 3 should be assumed.

CHAPTER X

Hazards to Food Stocks, Animals, Crops and Water Supplies

Introduction

10.1 To those doing civil defence tasks the external gamma radiation hazard from fall-out would be far greater than the risk of inhaling or swallowing fall-out particles (see paragraphs 8.11 to 8.13). On the other hand, the regular daily intake of food or water, if contaminated with radioactive fission products, might present a hazard. Tolerance limits of contamination must be specified but their application is a matter for radiological experts since the limits will depend upon how long it would be necessary to exist on the contaminated food or water supplies. War-time tolerances must of necessity be of entirely different magnitude from peace-time tolerances which are based on exposure throughout a lifetime.

Monitoring organisations

10.2 The first line of defence for the protection of the public would be the organisations for monitoring the degree of contamination and for controlling and distributing the available supplies of acceptably pure food and water. The Ministry of Agriculture, Fisheries and Food would be responsible for food supplies and for giving radiological advice and help to farmers* in an emergency. Water undertakers are responsible for the supply of drinking water, and the Ministry of Housing and Local Government in England and Wales and the Department of Health in Scotland have a general responsibility in this field. The agents of these bodies would need and would expect full co-operation from civil defence personnel who should have, therefore, some knowledge of the problems involved and of possible protective measures.

Solubility of fission products

10.3 A major uncertainty is the solubility in water of the radioactive components in fall-out or the ease with which they can stick on wet surfaces. Apart from one burst in shallow water which lifted large quantities of bottom mud at Montebello in 1952, trials of surface-burst nuclear weapons have taken place either on desert sand (fused, glassy, insoluble particles) or on coral which is similar to limestone and which usually results in a flaky fall-out with easily soluble or transferable radioactivity. One can only guess the nature of fall-out particles from weapons burst on other types of ground, e.g. saturated clay, and how much of the radioactive matter would dissolve or be dispersed in the water. The fused and semi-fused particles as well as the larger particles of earth, sand and dust would sink to the bottom of a river or reservoir, and only soluble radioactive matter held loosely on the surface of the particles would dissolve and diffuse slowly into the bulk of the water.

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* See "Home Defence and the Farmer", published in 1958 by H.M. Stationery Office, price 1s. 0d. net.

Retention of fission products in the body

10.4 The solubility of the various fission products is important because it facilitates their entry into the blood stream to be disseminated in the body tissues or accumulated in some specific organ which may then be irradiated for a considerable number of years. For example, about one-fifth of the radio-iodine taken into the body accumulates in the thyroid gland* in the front of the neck.

However, the radiological half life (see paragraph 3.1) of this radio-iodine is only about 8 days, and it will have virtually decayed within a month. At the other extreme, a quarter of the radio-strontium taken into the body accumulates in the growing parts of the skeleton. It has a relatively long radiological half life of about 28 years and it also remains in the bone for many years. But the bone is a living thing continuously changing, and this applies to the radio-strontium which has a biological half life of about 11 years; this means that half the amount present at any time will have been eliminated from the body in about 11 years. Radio-caesium, unlike strontium, is not retained for long in the body and half of the amount taken in spreads throughout the muscles and tissues: it has a long radioactive half life of about 33 years but it is soon eliminated from the body (in fact, in two to three months since its biological half life is only 17 days).

10.5 The soluble components of fall-out, when they get into the body, pass into the blood stream from the skin, the lungs or the gastro-intestinal tract. Some two-thirds of inhaled fall-out particles will be coughed up and swallowed. The insoluble components will pass through the gastro-intestinal tract in about 30 hours of which about 26 hours will be spent in the large intestine. During this period they will irradiate the body with gamma radiation and the linings of the stomach and intestines with alpha and/or beta particles as well (paragraph 8.6). This may result in some inflammation and temporary gastric disturbances.

Significance of internal contamination

10.6 The radiation dose-rate from internal body contamination is, of course, infinitesimal compared with that from a widespread fall-out field, but it may be concentrated very close to small groups of vital body cells which may be irradiated for long periods. Only a few radioactive isotopes among the fission products, mainly those mentioned in paragraph 10.4, are significant in this respect. The risks involved can be assessed and it is essential to be able to view them in proper perspective in relation to many other unavoidable and much greater hazards of war.

Effect of fall-out on sources of drinking water

10.7 It must be emphasised that *gamma radiation does not in any way affect the purity or impair the potability of water*. The main purpose of the monitoring organisation would be to prevent the water from becoming a means of transporting radioactive matter into the human body. It is proposed to cut off, from the public, sources of water

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* Infants have much smaller thyroids and drink more milk than adults so that the risk of injury to the thyroid from radio-iodine in milk is very much higher for infants than for adults (see paragraph 8.12).

which become contaminated with fall-out above the tolerance level, leaving householders dependent on their own reserve supplies until such time as arrangements could be made for affected areas to receive alternative supplies, possibly by carting.

10.8 The main sources of drinking water in the United Kingdom are underground wells, rivers and impounding reservoirs fed from catchment areas. Wells and reservoirs each supply slightly more than a third of the population and rivers just under a third. *Underground sources* of water would, in general, be free from contamination but if the water is stored in open reservoirs there is a possibility of contamination. *In rivers* many of the fall-out particles would sink to the bottom or be held in mud and vegetation. Some of the active material which dissolves in the river water would be absorbed by mud and vegetation and the rest would ultimately flow to the sea. It seems reasonable to expect that river water would not be contaminated above emergency levels for long periods.

10.9 The large surface areas of *impounding reservoirs* are open to fall-out and the contamination of the water to hazardous levels is therefore possible. It is worth noting in this connection that one of the normal methods of water softening in current use in some industries, known as the base or ion-exchange process, could remove nearly all the radioactive matter dissolved from fall-out.

10.10 As explained in paragraph 10.7 it is proposed to cut off water which is contaminated above the tolerance levels. It is not possible to say for how long, because this would depend upon the level of contamination and the availability of other supplies of fresh water. It would be important for householders to store as much water as possible in order to provide a reserve supply for emergency use. The utmost economy should be exercised in the use of these supplies, some of which should be kept near the emergency refuge.

Industrial cooling water

10.11 Many industrial installations have a small reservoir and recirculating system for cooling water. If possible, the exposed water surfaces should be covered to prevent entry of heavy fall-out. If fall-out did enter, much of it would sink to the bottom or become absorbed in growths on the bottom and walls of the reservoir, and if the depth of water was more than three to four feet, it would be an adequate radiation shield. Provided the water was *not* used for human consumption the soluble radioactive content would present a negligible external radiation hazard when the cooling system was in use.

Sewage disposal

10.12 The harmless disposal of sewage normally depends at some stage on the action of micro-organisms. The risk of injury to the micro-organisms by fall-out is negligible. The main hazard would be possible leakage of radio-strontium, radio-barium and radio-caesium through the sewage plant into a river used as a source of drinking water not far downstream.

10.13 In the event of widespread fall-out in built-up areas, much of the fall-out might be washed by rainfall or in decontamination operations down the gutters and into street drains. To a large extent it would be trapped there until it decayed but it would not constitute a significant hazard to the public because of the depth of the drains underground. Collaboration of sewage, water and river authorities would be necessary to dispose of the contaminated drainage with least harm to water supplies and to sewage plant, e.g. by arrangement to by-pass it through storm overflows and to stop drawing drinking water supplies from the river during this period.

Food stocks

10.14 It is not the purpose of this pamphlet to review the administrative problems which would face the Ministry of Agriculture, Fisheries and Food after the widespread destruction and the disruption of communications and transport consequent on a nuclear attack on this country. Official reviews of these problems and of the steps being taken to deal with them have been published elsewhere*. This section will be confined, therefore, to basic advice for the protection of people and animals, and their sources of food.

10.15 Many communities isolated by heavy fall-out would have to rely on their available local stocks of food, including that in houses and retail shops, for an indefinite period until arrangements could be made for emergency feeding. It is of vital importance, therefore, that no food be wasted. The monitoring organisation will separate clean from contaminated food and unless the latter is perishable it must be retained until specialist advice has been obtained on how to salvage the maximum amount.

10.16 *Gamma radiation has no harmful effect on foodstuffs* except at dose-rates far in excess of those likely to be encountered where food survives any nuclear detonation. Neutron bombardment might induce some radioactivity but this would not occur outside the area of complete destruction and by the time such food could be salvaged it would be safe to consume. The only significant hazard to food, apart from growing crops, would be the deposition on it of radioactive fall-out which might eventually find its way into the human body. Food contained in impervious wrappings would be safe to eat provided that the wrapping had not been damaged physically. It would be safe to eat provided care was taken to remove the fall-out from the exterior of the container and to prevent contamination of the contents when the container was opened. This would apply also to food in paper wrappings provided the paper had not been soaked with wet fall-out or by subsequent rain (see paragraphs 1.19 and 10.3).

Growing crops

10.17 Heavy fall-out would, of course, preclude any possibility of lifting crops until the dose-rate had fallen sufficiently to permit limited and calculated exposure periods. Crops contaminated with fall-out would need careful handling to prevent the transfer of radioactive matter to the skin, hair or clothing and thence into the mouth or into cuts and abrasions.

10.18 Root crops should be fit for consumption after thorough washing, and so should peas and beans in the pod if the pods were washed before, and the peas after shelling. The hearts of cabbage, sprouts and lettuce should be thoroughly washed after discarding the outer

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* See footnote to paragraph 10.2.

leaves. Hard skin-fruits could be washed and peeled but soft fruits should be discarded. Flour produced from cereal contaminated with fall-out would contain only a small fraction of the original contamination.

10.19 The effect of fall-out on crops would depend upon their state of growth at the time: if they were in the early stages of growth they would absorb radioactive matter through the root system as well as becoming contaminated on the leaves or other parts above ground. The contamination of the soil present farmers with many other long-term problems. Most of the radioactive components in fall-out would not be washed deeply into the soil but would be retained in the top few inches, and it would be generally advantageous to dig or plough the contamination deeply into the soil and to add lime where there was lime deficiency as this would reduce the uptake by plants of any traces of radioactive strontium which might be present.

Livestock

10.20 Livestock are affected by fall-out and by radiation in much the same way as human beings. They can suffer radiation sickness, skin burns from fall-out and internal injury to the gastro-intestinal tract when fall-out is swallowed in food or water. As in human beings radio-iodine accumulates in the thyroid gland and radio-strontium accumulates in the bones of animals. In general, the lethal dose depends on size, but among larger animals cattle and horses are slightly more sensitive and sheep and pigs slightly less sensitive than human beings. Except for dairy cattle and breeding stocks, the long-term effects of radiation would be of little consequence because, normally, the animals would be slaughtered long before these effects could become manifest.

10.21 The flesh of animals exposed to initial gamma flash or to residual radiation from fall-out (unless they are in the last stages of illness) would be fit for human consumption provided the bones and the offal were discarded.

10.22 Where practicable, animals should be put under cover and fed with clean food and water, priority being given to breeding stock and dairy cattle.

Milk and eggs

10.23 Cattle secrete in the milk a considerable proportion of the radio-iodine and radio-strontium they absorb. It is anticipated that over large areas of the country the milk produced by cows grazing in the open would be unsafe for infants fed entirely on milk. If facilities were available it would be possible to save contaminated milk by converting it into butter and cheese and storing these products until the radioactivity had decayed, or, in the last resort, by feeding it to animals, e.g. pigs and poultry.

10.24 The risk of serious contamination in eggs is relatively small, and the risk would have to be accepted when there was a shortage of food. In cases of doubt (when poultry were known to have eaten heavily contaminated feed) the eggs should be preserved and stored until they could be tested for radioactive content.

CHAPTER XI

Summary of Methods of Protection and Decontamination for the Individual

Protective preparations to be taken in an emergency

11.1 All windows and skylights that have a direct view of some part of the sky should be whitewashed. The whitewash would reflect much of the heat of the fireball and so help to stop the heat rays from getting inside the building and setting fire to inflammable objects.

11.2 Attics and lofts should be cleared of all inflammable materials. In other parts of the building, anything inflammable should be removed from the vicinity of windows and other openings, e.g. piles of newspapers on a window-seat or a table near a window.

11.3 Curtains should be removed from windows or made flameproof by soaking in a fire-retardant solution*.

11.4 Baths should be kept full of water and buckets of water should be placed in all rooms for the quick extinction of fires, glowing wood, fabrics, etc.

11.5 The family refuge should be prepared. This should be in the basement or cellar if there is one; otherwise, an innermost room on the ground floor, farthest from external walls and protected by the maximum total thickness of walls on all sides, should be chosen. If a last-war garden shelter is available, the earth-cover should be thickened to about 3 ft.

11.6 The windows of the refuge room should be blocked up or shielded so that they give protection as good as that from the rest of the walls of the refuge, e.g. by erecting a "wall" of sandbags or of boxes filled with earth or sand built up outside the room up to a height of 6 ft. above floor level (or to the top of the window if it is overlooked by trees or by higher ground within 100 ft.).

11.7 Stocks of first aid materials and adequate food supplies for about one week should be collected in or near the refuge: food should be in tins or in waterproof containers or, where appropriate, wrapped in greaseproof paper and put into tins to protect it from plaster, glass and other debris if the house is damaged.

11.8 A supply of drinking water should be stored in jars or bottles, preferably sealed, but at least covered to keep out dust.

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* Suitable solutions for household use are 3 lb. boric acid plus 2 lb. sodium phosphate (or, alternatively, 3 lb. borax plus 2 lb. boric acid) dissolved in 3½ gallons of water. Curtains and fabrics should be thoroughly soaked in the solution and the excess liquid squeezed out before they are rinsed and dried.

11.9 Should there be no indoor W.C., sanitary facilities for use during occupancy of the refuge should be provided.

11.10 In large buildings, natural ventilation should be considered in choosing refuge rooms particularly in a basement. While electrical power remains available, fans should be used either to expel the air from the refuge room through an external vent or to draw fresh air from other spaces within the building. If the building has a forced ventilation system, downward-facing air inlet pipes should be fitted externally and the ends covered with a fine wire gauze screen. If the electrical power fails, sufficient natural ventilation can be achieved if the selected refuge room has an ordinary fireplace and chimney or if it has a ventilation grid near the ceiling opening to the external air, or to some other large space within the building and if, at the same time, the door of the refuge room and all other internal doors on that floor are kept open.

If neither of these conditions is fulfilled, holes could be made near the ceiling in one of the internal walls of each refuge room, opening into larger spaces within the building.

11.11 Bunks or mattresses should be provided as liberally as possible in each refuge room: a person needs nearly twice as much oxygen and exhales twice as much carbon dioxide when sitting as when sleeping and still more when standing and walking about.

Protective measures during and after a nuclear attack

People caught in the open

11.12 No one should be out of doors after a warning of attack had been given except those whose duty required them to do so. Such people would have a specific refuge in mind or at least would know at any moment how to obtain the best protection against the various effects of nuclear weapons.

11.13 If you were out in the open and you saw the flash of the explosion of a nuclear weapon, you might be temporarily blinded but you should try immediately to get behind the best nearby cover that was available, so as to obtain protection from the heat rays and from the effects of the subsequent blast wave and flying debris. Cover on all sides as well as overhead would, of course, be the best: failing that, you should get behind a wall or other solid structure. If there was no other cover, you should lie face down on the ground (in a ditch, gutter or other depression, if possible) using your arms, or a coat or jacket, to cover the head and any exposed skin.

11.14 After the blast wave had passed there would be ample time before the start of fall-out (about half an hour in the case of a large bomb) to enable you to get into a prepared refuge against the fall-out.

People in refuges

11.15 After the blast wave had passed a quick inspection should be made of all rooms in the house or building, including spaces under the roof. Fires which had started and all glowing wood or other material should be extinguished.

11.16 Urgent repairs or weatherproofing which could be completed within half an hour should be done. Curtains or sheets should be tacked over broken windows to keep gross amounts of fall-out from being blown into the rooms. There would be no cause to worry about small amounts of fall-out getting into damaged parts of the house—provided it was not allowed to get into food or water consumed in the refuge room. If dust was visible later in any room it should be swept and dumped outside.

11.17 Except possibly in the area damaged by a nuclear explosion, two separate fall-out warnings* would be given, the *first* to indicate that fall-out was likely, i.e. might arrive at any time after 1 hour and the *second* when it was imminent. After the blast wave had passed and until the imminent warning was received all necessary help and first aid should be given to neighbours.

Protective measures after fall-out had ceased

11.18 You should remain in the refuge for the first 2 days after the explosion or until you had been told that your district was free from radioactive fall-out. If you did not receive any instructions you should stay in your refuge as long as possible (i.e. you should not remain any longer than was necessary in other parts of your house). Above all, you should not go out of doors until you received further instructions. If you were well inside the fall-out area it might not be possible to get further information or instructions to you until the third or even fourth day after the explosion.

11.19 These instructions would tell you how many hours you might safely spend each day out of your refuge (*a*) in other parts of your house (where the shielding is less) and (*b*) outdoors getting food rations and other needs for your family. They would also tell you WHERE and WHEN to go for these food, water and medical supplies so that you would not have to wait and be exposed unnecessarily to a high dose-rate. When you had to go outside for this purpose you should use, if possible, quick means of transport (bicycle or car) so that you could reduce your exposure outdoors to the absolute minimum.

11.20 The advice given to you would depend on the type of house you lived in and amount of shielding it afforded against gamma radiation. The advice would be designed to let you have as much freedom as possible without incurring radiation sickness. It would be essential that you and all members of your family should follow the advice strictly.

11.21 If you did not receive instructions before the end of the third day, it might be because you were in an area of high dose-rate. If so, it would be all the more necessary for you and your family to remain in your refuge room, to spend as little time as possible in other parts of the house and to avoid outdoor exposure until you had been told what you might safely do.

11.22 If the dose-rate in your area was above a certain intensity you would be given advance notice of arrangements to clear people from the area street by street or maybe house by house. You would be told exactly WHEN and WHERE you would be collected. You would

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* See paragraphs 3.4, 3.5 and 8.9.

have to be ready at the exact time and place; otherwise, you might imperil not only your own life but the lives of those who were accepting heavy risks, carefully calculated in time, in trying to rescue you and your family and neighbours.

Decontamination of skin and clothing

11.23 It has been explained in paragraphs 8.11 to 8.13 that the hazard from contamination on the skin and clothing is a relatively minor one compared with the hazard caused by the general field of gamma radiation from fall-out. If you suspected that you had been contaminated with radioactive fall-out you should use the following decontamination procedure as soon as you got to your refuge:—

(*a*) Remove all outer clothing and place it in a room or cupboard separate from your refuge room. It would be useful to have bags of polythene or similar material into which contaminated articles could be placed since the bags could be handled later with a much smaller risk of spreading the contamination. In removing the outer clothing, care should be taken *not* to shake it as this would disperse radioactive dust unnecessarily into the atmosphere.

(*b*) The hands, head and neck should then be thoroughly washed and scrubbed with soap and warm water while bending over a hand basin. This washing should be repeated at least once, taking care to brush under the nails thoroughly.

11.24 If you had been covered heavily with fall-out, you might develop skin burns on the exposed parts of the body but these would heal normally provided you had not also been exposed to excessive doses of gamma radiation.

11.25 Contaminated clothing can be cleaned to a very considerable extent (almost complete removal of fall-out particles) by either or, where appropriate, both of the following methods:—

(*a*) Removal of dust from the clothing by means of an efficient household vacuum cleaner, or

(*b*) Soaking and stirring the clothing in a solution of household detergent—either 5 minutes in a washing machine or 5 minutes vigorous stirring (with a suitable stick) in a bath or bucket—followed by thorough rinsing in clean water.

Decontamination of roads and paths

11.26 In urban districts, arrangements might have to be made to decontaminate certain roadways and hard paths around houses which had to be used soon after the two-day refuge period and residents might be asked to help. A certain amount of decontamination could be achieved after a land burst by hosing or swilling contaminated hard surfaces with water if drains are available.

APPENDIX 1

Atoms and the structure of matter: some definitions

1. A little knowledge of the structure of matter helps towards an understanding of the effects of nuclear weapons. Matter consists of an assembly of atoms of various *elements* interspersed in space at relatively great distances from one another. The metals iron and aluminium, the non-metal sulphur and the gases hydrogen, oxygen and nitrogen are among the more common of the 102 different elements now known and some of these elements like plutonium are man-made. Each element has characteristic chemical properties by which it can be distinguished from all the other elements.

2. An *atom* of an element is the smallest particle which can exhibit the chemical properties of that element. For example, if single atoms of iron were broken up, the pieces would have the recognisable properties of quite different elements. Atoms are exceedingly small, far smaller than the limits of visibility under a microscope: nevertheless, most of the matter contained in each atom is concentrated in a central nucleus which is about 10,000 times smaller. A nucleus always carries one or more positive electrical charges and, in the normal state, it is surrounded by a cloud consisting of an equal number of negatively charged particles called *electrons*, so that the atom as a whole is electrically neutral. These electrons can be imagined as moving in orbits around the nucleus like planets around the sun.

3. A nucleus contains two main types of fundamental particle each of which is about 1,840 times as massive as the electron:—

a *neutron* with no electrical charge,
a *proton* with one positive charge.

Because of the repulsive forces between positive charges, nuclei cannot approach one another very closely, but an uncharged neutron can approach and hit another nucleus without being repelled. The energy released in an atomic pile or in the detonation of a nuclear weapon is part of the large quantity of binding energy which holds the particles together in the nucleus.

4. The chemical properties peculiar to each element are determined by the number of protons, i.e. the number of positive charges in the nucleus of each atom. Consequently, the elements can be numbered consecutively from the lightest element hydrogen (one proton with an electron in orbit around it) up to the largest atoms of the recently discovered element nobelium which have a nucleus containing 102 protons surrounded by a cloud of 102 electrons.

5. It is not possible for a nucleus to consist of protons alone, because the repulsive forces between the positive charges would make them fly apart: in nuclei containing more than one proton this is prevented by the presence of the neutrons and by the attractive forces between the different fundamental particles in close proximity. The atoms of all the elements, with the exception of the simplest type of hydrogen atom, contain at least as many neutrons as protons and the larger the nucleus, the greater is the excess of neutrons over protons needed to hold the nucleus together.

6. All atoms of one element contain the same number of protons but they may have different numbers of neutrons. Thus, several atomic species of the same element are possible and these are called *isotopes* of that element. There is a limit to the number of possible isotopes of each element and those which contain too many or too few neutrons are unstable or radioactive and disintegrate sooner or later, by expelling neutrons or electrons (resulting from the conversion of neutrons to protons) in order to restore the balance in the ratio of neutrons to protons needed for stability. Under those circumstances the electron expelled at high speed from the nucleus is called a beta particle. A succession of changes or disintegration may occur before a stable nucleus is formed and, in many of these, excess energy may be emitted also in the form of gamma rays, an electromagnetic radiation like light or X-rays but of much shorter wavelength. A frequent occurrence, particularly among heavier radioactive atoms, is the expulsion of an alpha particle which is, in fact, the nucleus of the gaseous element helium (containing two protons and two neutrons) without its two outer electrons.

7. The element uranium found in nature is a mixture of isotopes but most of it consists of atoms with 92 protons and 146 neutrons, i.e. a total of 238 mass units in each nucleus: hence, this isotope is referred to as U-238. Another isotope, U-235, with 92 protons and 143 neutrons found in natural uranium to the extent of about 0·7 per cent., was the explosive material used in the first atomic bomb after separation from the U-238.

8. The plutonium isotope Pu-239 (94 protons plus 145 neutrons) is an artificial one produced in an atomic pile from U-238 and the isotope of uranium U-233 is produced similarly from thorium. All three of the above isotopes can be used as explosive charges in nuclear weapons.

9. Uranium and plutonium are heavy metals near the end of the consecutive list of elements. At the other end of the list, the lightest element hydrogen has two additional rarer isotopes and all three have nuclei containing only one proton. One of these is called deuterium because of its two units (one proton plus one neutron) and the other tritium because of its three units (one proton plus two neutrons). Both deuterium and tritium are used directly or indirectly as the nuclear explosive charge in a thermonuclear or hydrogen bomb.

Nuclear fission

10. The isotopes U-233, U-235, and Pu-239 are radioactive and their atoms disintegrate by expelling alpha or beta particles or gamma rays from the nuclei. But there is another way in which these atoms can break up. When they capture, or are hit by, a neutron, each nucleus splits up into two not quite equal parts. At the same time, two or three other neutrons are released. This fission process is responsible for the large quantities of nuclear energy released in an atomic pile or in the detonation of a nuclear weapon. The fissile charge even in a small nuclear weapon although it may weigh only several pounds, contain multiple millions of atoms and these do not all split up in quite the same way. The products of fission contain therefore about 200 different radioactive isotopes of about 35 elements.

Critical sizes of fissile charges

11. When a piece of fissile material is below a certain critical size, a few of the atoms are continually undergoing fission but more neutrons escape from its surface than are produced in fission and an increasing chain of fissions is not built up. If several pieces of fissile material, totalling more

than the critical amount, are suddenly brought together inside a strong container or tamper a nuclear detonation results. The critical size depends upon a number of factors including the density of the material, i.e. whether it is solid metal or in porous, spongy form and also upon the nature of the container and whether it absorbs neutrons or can reflect them back into the fissile charge.

12. Published information suggests that an unconfined sphere of U-235 metal of about 6½ in. diameter and weighing about 48 kilograms would be a critical amount: this would be reduced to about 4½ in. diameter (16 kg.) for a U-235 sphere enclosed in a heavy tamper. The critical sizes for U-233 and Pu-239 have not been disclosed but are somewhat smaller than for U-235. The increasing mechanical complication of bringing together, rapidly and simultaneously, a number of sub-critical pieces of fissile material sets a practical limit to the power of nuclear fission weapons.

Nuclear fission and thermonuclear weapons

13. A temperature of several million degrees centigrade is reached in the detonation of a nuclear fission weapon. At this temperature atoms are stripped of most of their surrounding cloud of electrons and the nuclei move at very high speeds experiencing many collisions with one another. Under these circumstances the nuclei of the rarer hydrogen isotopes deuterium and tritium have enough energy of motion to overcome the repulsive forces between their single positive electrical charges and they are able to fuse together. The energy released in the fusion of these two nuclei is about one-twelfth of that released in the fission of a single U-235 nucleus, but on an equal weight basis, the fusion energy is about two and a half times as large as the energy of fission of U-235.

14. In the process of fusion a neutron is released at a very high speed from each pair of reacting nuclei and it has enough energy to split the commoner atoms of U-238. Thus, if U-238 metal is used as the bomb case in a thermonuclear weapon the quantity of fission products will be increased many times. This type of weapon is the fission-fusion-fission type or so-called "dirty" bomb.

15. Deuterium and tritium as isotopes of the gaseous element hydrogen have to be liquefied at a very low temperature and maintained there for containment in a thermonuclear weapon. This is inconvenient although it has been reported that the first American H-bomb tested in 1952 was of this type. In later weapons the deuterium is combined chemically with the metal lithium in the form of a white powder. Each neutron (1 mass unit) released by the triggering fission bomb splits a lithium atom (6 mass units) into the non-radioactive gas helium (4 mass units) and tritium (3 mass units) and the latter fuses with the deuterium atoms present in the compound. There is no limit, other than the convenience of delivery, to the size of a fusion or thermonuclear weapon and it is claimed that lithium deuteride is less costly than fissile materials such as U-233, U-235 or Pu-239.

16. Helium gas, the main product of a thermonuclear detonation, is *not* radioactive (hence the expression "clean" bomb) but the very high speed neutrons which are also emitted collide with other atoms, e.g. they collide with the nitrogen atoms in the atmosphere and release a very intense and penetrating form of gamma radiation (flash), and they may induce intense radioactivity in some of the ground material if the weapon is burst on the ground—but this decays rapidly in a few days.

APPENDIX 2

Scaling Laws

Shock waves

1. Blast damage from nuclear detonations depends primarily upon the peak pressure in the shock wave and the associated wind pressure but also to some extent on the duration of the shock wave. The peak pressure and wind pressure decrease rapidly with increasing distance from the explosion (see Table 22 below).

A comparison of the blast effects of two detonations W_1 and W_2 kilotons in power is best made at points of *equal peak shock pressure*. The comparison can then be made of the distances D_1 and D_2 of these points from the respective explosions, of the times t_1 and t_2 taken for the shock waves to arrive at these points and of the lengths of time (durations) L_1 and L_2 of the positive pressure phase at these points. All are related to the cube root of the weapon yield thus :—

(i) $D_2 = \sqrt[3]{\frac{W_2}{W_1}} \times D_1$

(ii) $t_2 = \sqrt[3]{\frac{W_2}{W_1}} \times t_1$

(iii) $L_2 = \sqrt[3]{\frac{W_2}{W_1}} \times L_1$

D_2 and D_1 must be in the same units as must also be t_2 and t_1 as well as L_2 and L_1.

Example: For weapons $W_1 = 20$ KT and $W_2 = 10$ MT.

$$\sqrt[3]{\frac{W_2}{W_1}} = \sqrt[3]{500} = \text{approximately } 8.$$

Hence $D_2 = 8\ D_1$; $t_2 = 8\ t_1$ and $L_2 = 8\ L_1$.

TABLE 22

Relation between static overpressure, wind pressure and wind velocity for detonation near sea level. (Taken from the U.S. publication " Effects of Nuclear Weapons (1957) ", page 78)

*Peak static overpressure** *(p.s.i.)*	*Peak wind pressure* *(p.s.i.)*	*Maximum blast wind speed* *(miles per hour)*
72	80	1,170
50	40	940
30	16	670
20	8	470
10	2	290
5	0.7	160
2	0.1	70

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* i.e. pressure above that of the atmosphere (14.7 p.s.i.). Reflected overpressures can be very much higher (paragraph 7.3).

Dimensions of the crater from a ground-burst weapon

2. The dimensions of the crater (without the lip) from a 1 KT weapon burst on saturated clay are: diameter about 210 ft. and depth about 18 ft. Scaling factors for various types of ground are given in Table 23 for a bomb of W KT yield. The diameter scales as the cube root and the depth as the fourth root of the weapon power.

TABLE 23

Crater scaling factors

Nature of the Ground	*Dimensions of crater without the lip*	
	Radius (feet)	*Depth (feet)*
Saturated clay ..	$105 \sqrt[3]{W}$	$18 \sqrt[4]{W}$
Dry soil	$63 \sqrt[3]{W}$	$25 \sqrt[4]{W}$
Hard rock	$53 \sqrt[3]{W}$	$20 \sqrt[4]{W}$

Note :—The radius of the crater with its lip is roughly twice that of the crater alone

$$\text{Volume of crater} = \pi \times (\text{radius})^2 \times \frac{(\text{depth})}{2}$$

Fireball dimensions

3. Maximum diameter $= 460\ W^{2/5}$ (in feet for W in KT).
There is no simple scaling law for thermal effects of weapons of different powers (see paragraphs 5.5 and 5.10).

Stabilised cloud: heights and dimensions

4. The following *scaling laws* hold *for detonations of* 100 *KT and upwards in power:* the cloud behaves as a flat disc of approximately constant thickness of 25,000 feet:—

Altitude of top of disc H (feet) $= 23{,}000 \log_{10} W$ (W in KT)
Altitude of base of disc B (feet) $= H - 25{,}000$
Diameter of disc (feet) $= 3{,}200\sqrt{W}$ (W in KT)

For detonations of less than 100 KT in power the cloud is more dome shaped (mushroom) and there is no simple scaling law. The few figures in Table 24 have been taken from pages 282 and 283 of the Report of the American Congress Hearings on 27th May to 3rd June, 1957, Part I (The Nature of Radioactive Fall-out and its Effects on Man).

TABLE 24

Cloud dimensions for less than 100 KT

Weapon power KT	*Mushroom cloud dimensions (feet)*		
	Height to top	*Height to base*	*Maximum diameter*
80	46,000	35,000	36,000
50	42,000	32,000	30,000
20	34,000	27,000	20,000

Contour areas

5. Areas within reference contours having the same dose-rate values scale in direct proportion to the fission yield of the weapon.

Time taken by particles of different sizes to fall from different altitudes

6. Notes: Fall-out within the limits of the downwind dose-rate contours is expected to consist mainly of radioactive particles within the size range of 350 to 75 microns (i.e. 0·35 to 0·075 millimetre). For a 10 MT weapon, the activity in the cloud will be almost entirely below 80,000 ft.

TABLE 25

Time in hours for particles of different sizes to fall to the ground from specified heights

Particle size—microns	*500*	*350*	*200*	*100*	*75*
Falling to ground from	hours	hours	hours	hours	hours
80,000 ft.	1.6	2.3	4.5	12	22
60,000 ft.	1.3	2.0	3.7	9.5	17
40,000 ft.	1.0	1.5	2.8	6.8	12
30,000 ft.	0.8	1.2	2.2	5.3	9

51222 Wt. 3642—R127 K140 4/63 St.S.

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