The Effects of
ATOMIC WEAPONS

The Effects of Atomic Weapons

PREPARED FOR AND IN COOPERATION WITH THE U. S. DEPARTMENT OF DEFENSE AND THE U. S. ATOMIC ENERGY COMMISSION

Under the direction of the

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CHAPTER I [1]

PRINCIPLES OF AN ATOMIC EXPLOSION

A. INTRODUCTION

Characteristics of an Atomic Explosion

1.1 The atomic bomb is a new weapon of great destructive power. It resembles bombs of the more conventional type in so far as its explosive effect is the result of the very rapid liberation of a large quantity of energy in a relatively small space. But it differs from other bombs in three important respects: first, the amount of energy released by an atomic bomb is a thousand or more times as great as that produced by the most powerful TNT bombs; second, the explosion of the bomb is accompanied by highly-penetrating, and deleterious, invisible rays, in addition to intense heat and light; and third, the substances which remain after the explosion are radioactive, emitting radiations capable of producing harmful consequences in living organisms. It is on account of these differences that the effects of the atomic bomb require special consideration.

1.2 A knowledge and understanding of the mechanical and radiation phenomena associated with an atomic explosion are of vital importance. The information may be utilized, on the one hand, by architects and engineers in the design of structures; while on the other hand, those responsible for civil defense, including treatment of the injured, can make preparations to deal with the emergencies that may arise from an atomic explosion.

1.3 During World War II many large cities in England, Germany, and Japan were subjected to terrific attacks by high-explosive and incendiary bombs. Yet, when proper steps had been taken for the protection of the civilian population and for the restoration of services after the bombing, there was little, if any, evidence of panic. It is the purpose of this book to state the facts concerning the atomic bomb, and to make an objective, scientific analysis of these facts. It is hoped that as a result, although it may not be feasible completely to allay fear, it will at least be possible to avoid panic.

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[1] Material contributed by G. Gamow, S. Glasstone, J. O. Hirschfelder.

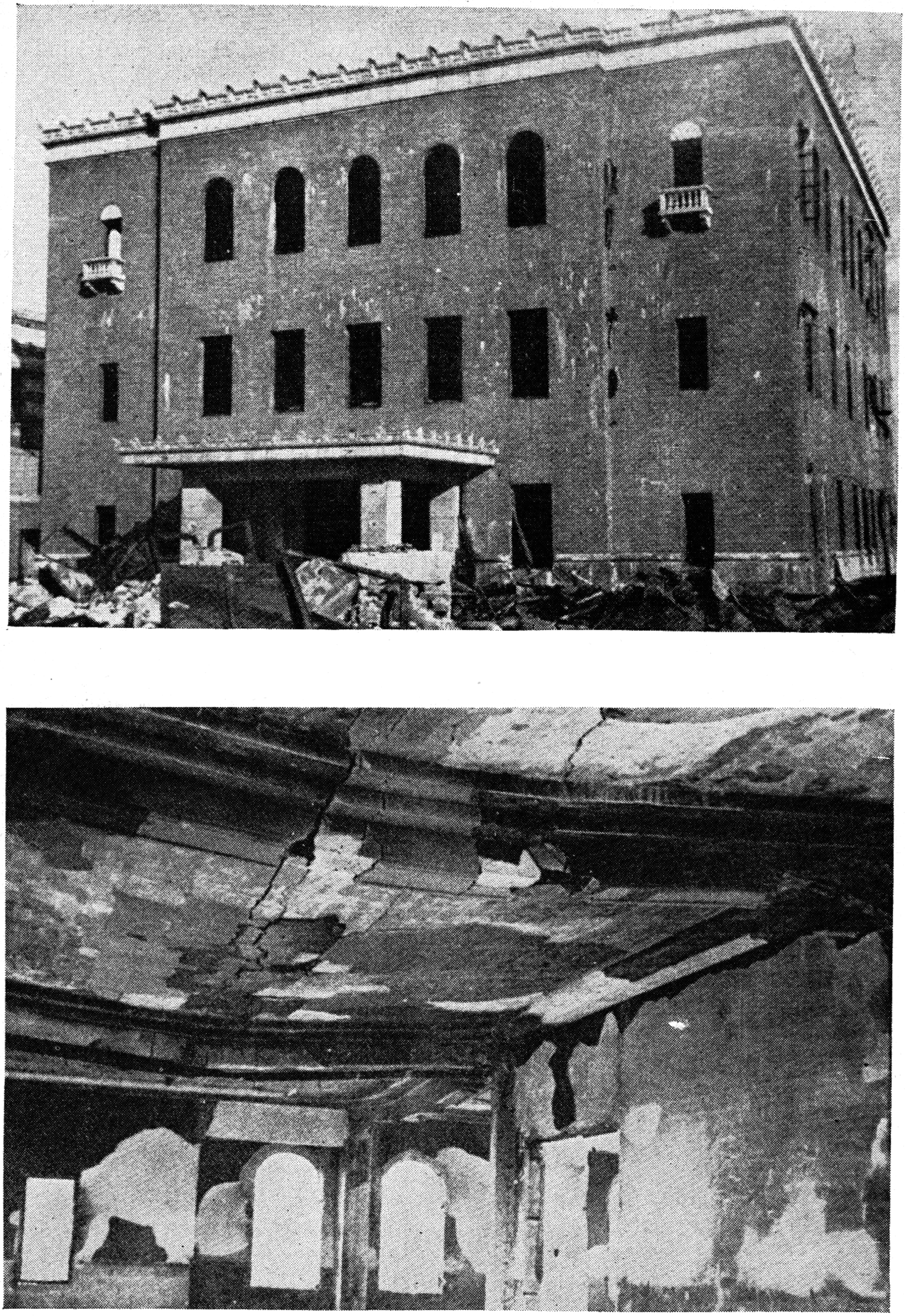
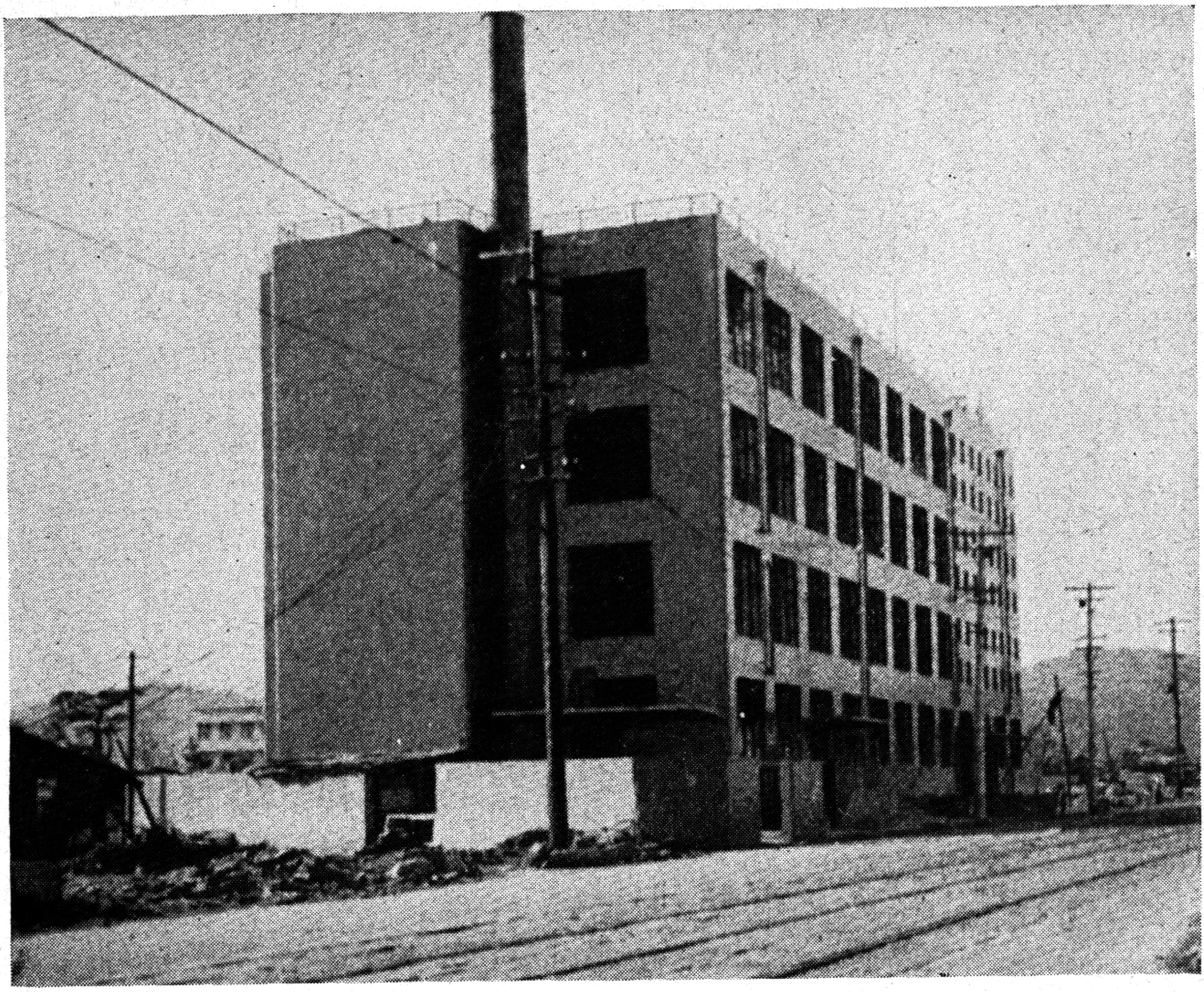


Figure 5.54a. *Upper photo:* Reinforced-concrete frame building, 700 feet from ground zero, 2,100 feet from point of explosion; external walls intact. *Lower photo:* Interior of above burned out; note sagging of roof and spalling of plaster by fire.



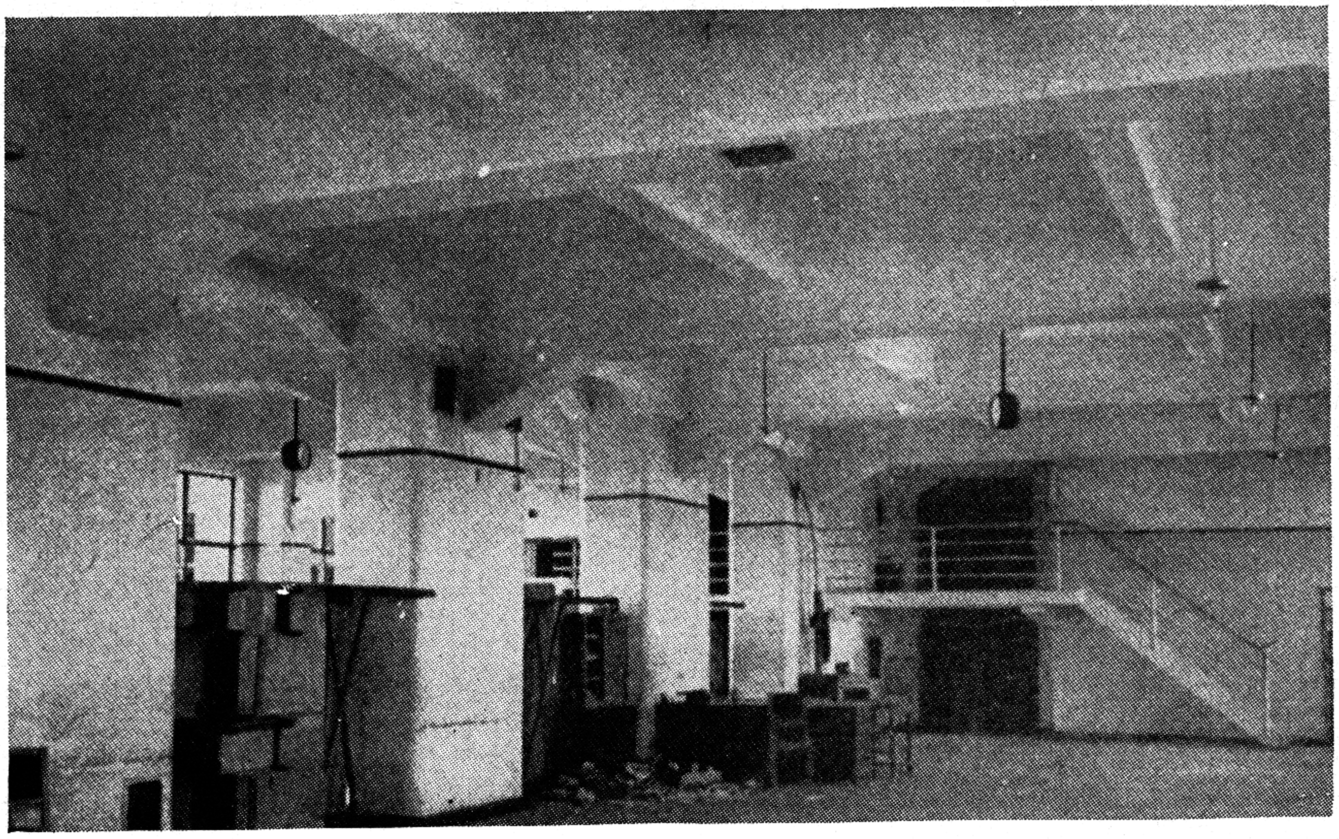


Figure 5.54b. *Upper photo:* Reinforced-concrete frame building, 5,300 feet from ground zero. *Lower photo:* Interior of above practically undamaged, except for windows.

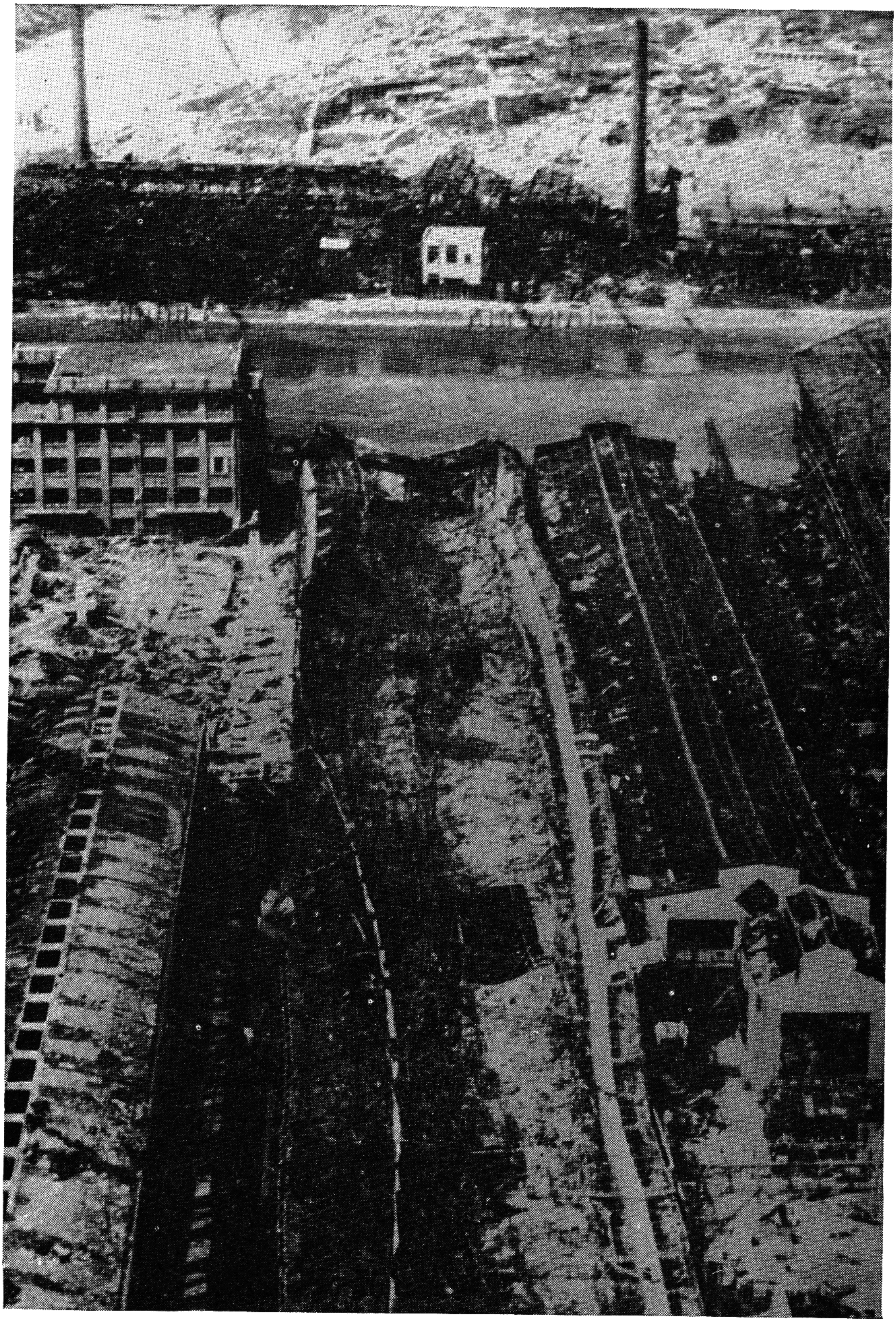


Figure 5.57. At left and somewhat back of center is shown the only multistory steel-frame building exposed to atomic bombs. It was in Nagasaki, 4,500 feet from ground zero.

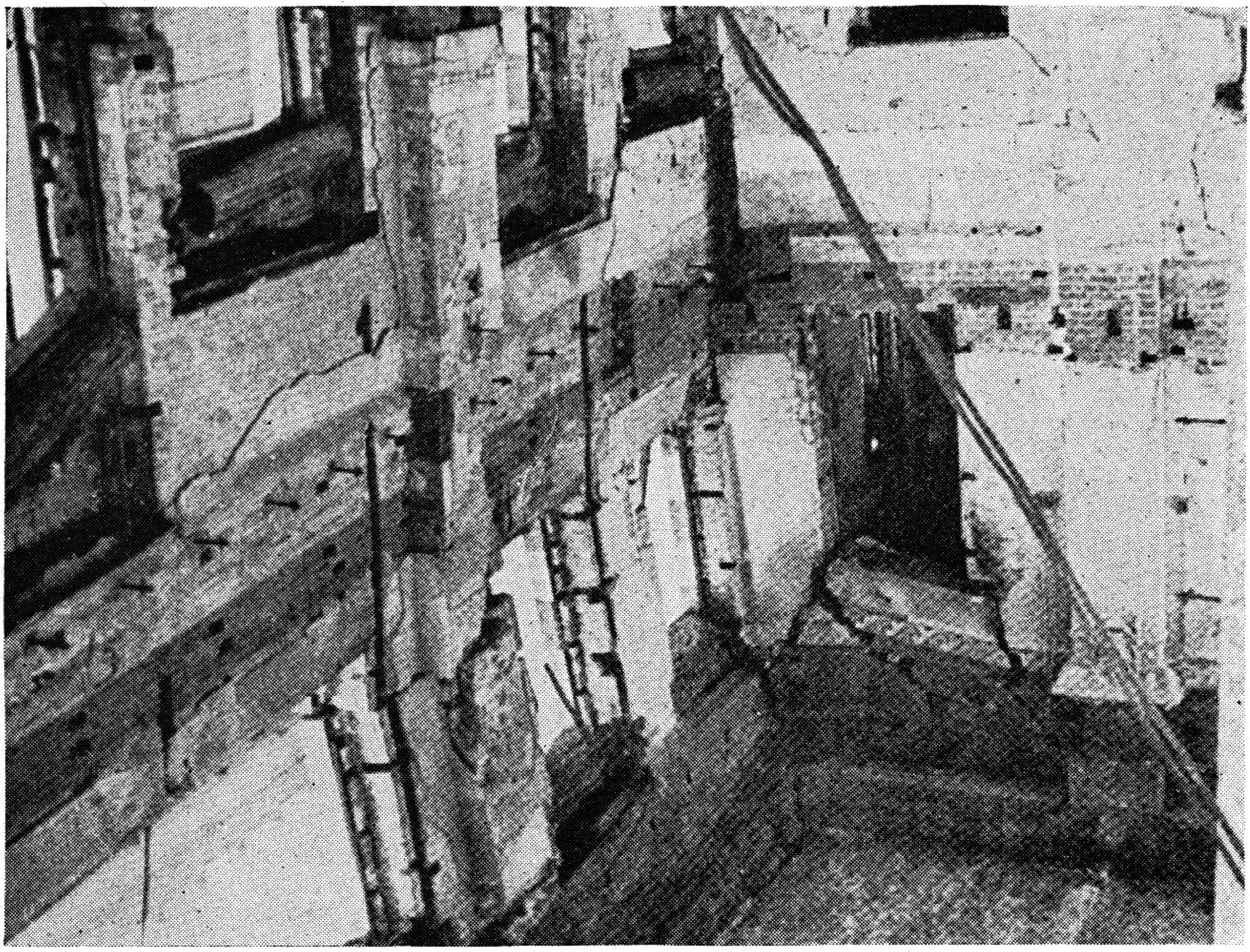


Figure 5.65a. *Upper photo*: Building with load-bearing walls, 600 feet from ground zero, 2,100 feet from the point of explosion. *Lower photo*: Interior of above, showing buckling of wall and combustible material burned out.

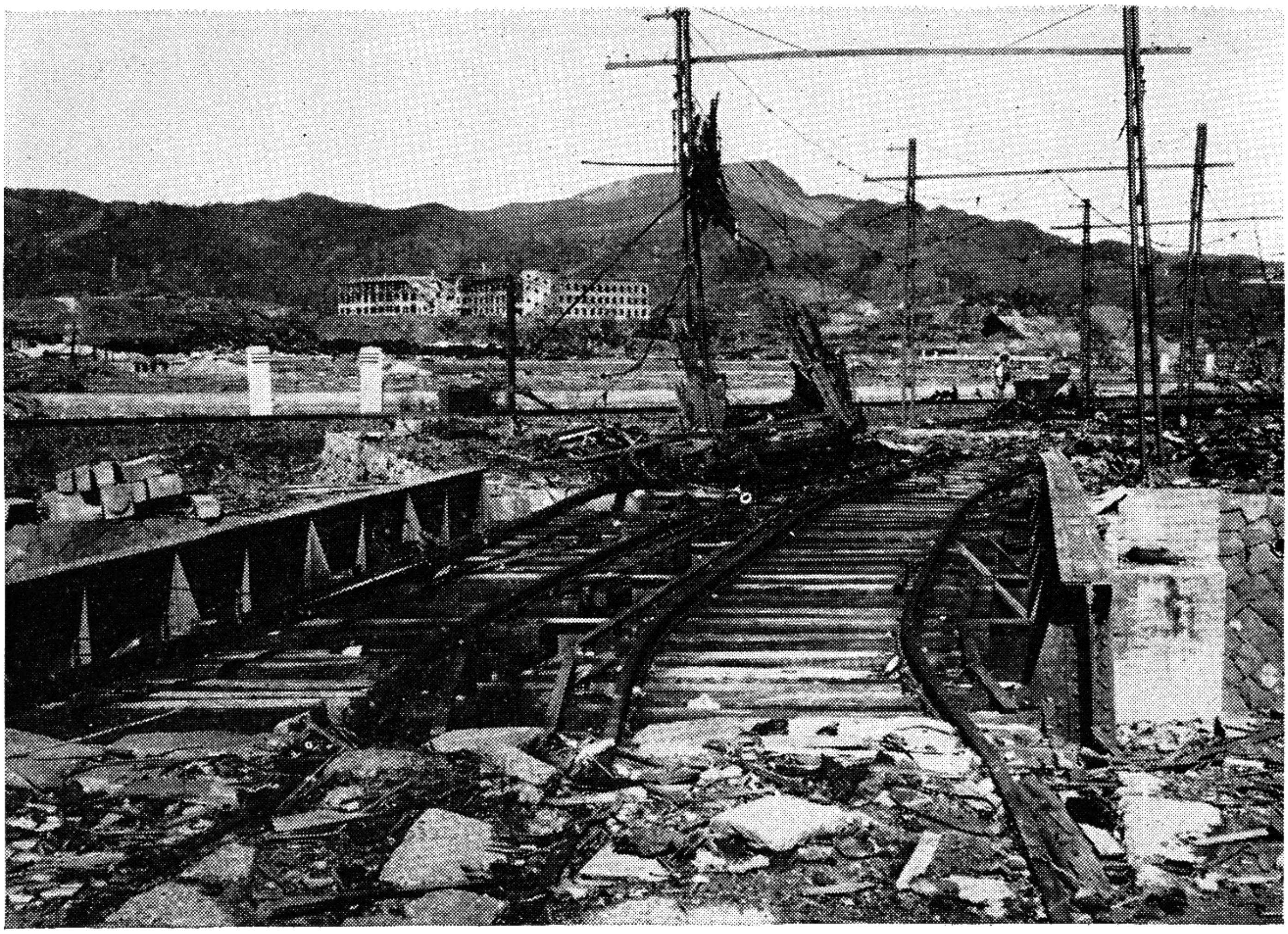


Figure 5.67b. Steel-plate girder, double-track railway bridge, about 840 feet from ground zero, 2,150 feet from point of explosion. The plate girders were moved about 3 feet by the blast; the railroad tracks were bent out of shape and trolley cars were demolished, but the poles were left standing.

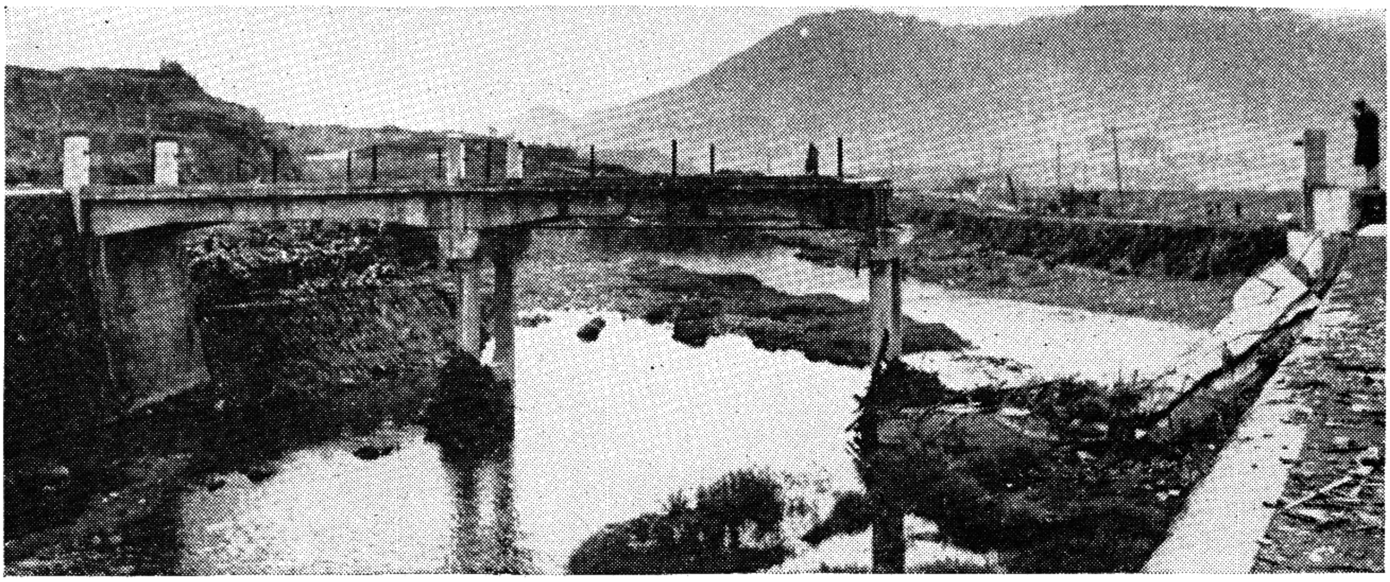


Figure 5.67c. Reinforced-concrete bridge with T-beam deck, 2,330 feet from ground zero. Part of deck was knocked off the pier and abutment by the blast, causing one span, 35 feet long, to drop into the river. The remainder of the bridge was almost undamaged.

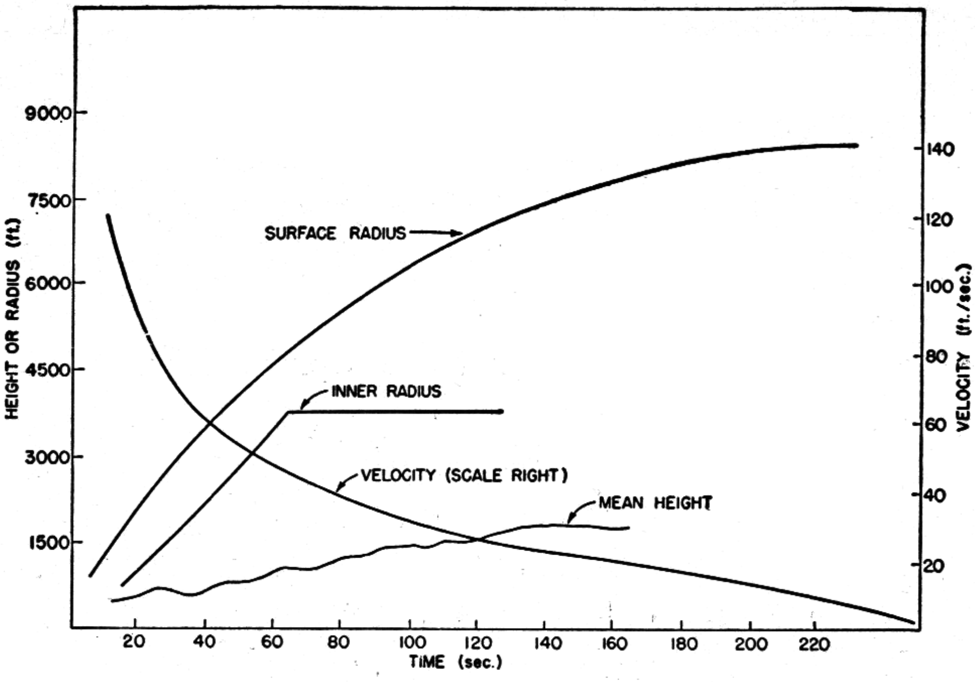


Figure 4.71. Dimensions and velocity of base surge as functions of time.

4.72 For velocities in the upwind or downwind directions, the wind velocity of 300 centimeters per second must be subtracted from or added to the value for V given in equation (4.71.1). After 200 seconds, the radial velocity diminished rapidly to zero which was attained at about 240 seconds.

4.73 The mean outer radius corresponding to equation (4.71.1) is given by

$$R=\frac{aK^2+aKt+Ct}{K^2+Kt}, \tag{4.73.1}$$

where $a=4\times10^3$. Introducing numerical values for K and a, it is found that

$$R=\frac{3.6\times10^5+3.7\times10^5t}{90+t} \text{ cm.} \tag{4.73.2}$$

Beyond 3 minutes the radius did not appreciably increase and these equations no longer held.

4.74 If R_t is the surge radius at time t, and U is the wind velocity, the distance from the explosion point to the upwind edge of the base surge at any time t will be given by

$$X_{ut}=R_t-Ut, \tag{4.74.1}$$

and in the downwind direction by

$$X_{dt}=R_t+Ut. \tag{4.74.2}$$

8.90 Apart from the effect of the base surge, radioactive contamination will result from the rain produced by the fall-out. There has been some difference of opinion concerning the relative contributions of the base surge and the fall-out to the total radiation dosage. The question is of practical significance, since some protection of personnel from ordinary rainfall, as from the fall-out, is possible in the open. But since the base surge is a cloud which moves laterally, protection from its radiation is not so simple. There is no doubt that at Bikini, the base surge was very significant, and it appears that, in general, both base surge and fall-out will contribute to the radiation dosage, the relative amounts depending on the depth of burst, depth of water, and other conditions.

8.91 From measurements made at the time of the Bikini "Baker" test, it has been possible to draw some general conclusions with regard to the integrated or total radiation dosage received at various distances from surface zero. Actually, about 90 percent of this dosage was attained within 30 minutes of the explosion. The results are represented in the form of radiation dosage contours in Figs. 8.91a,

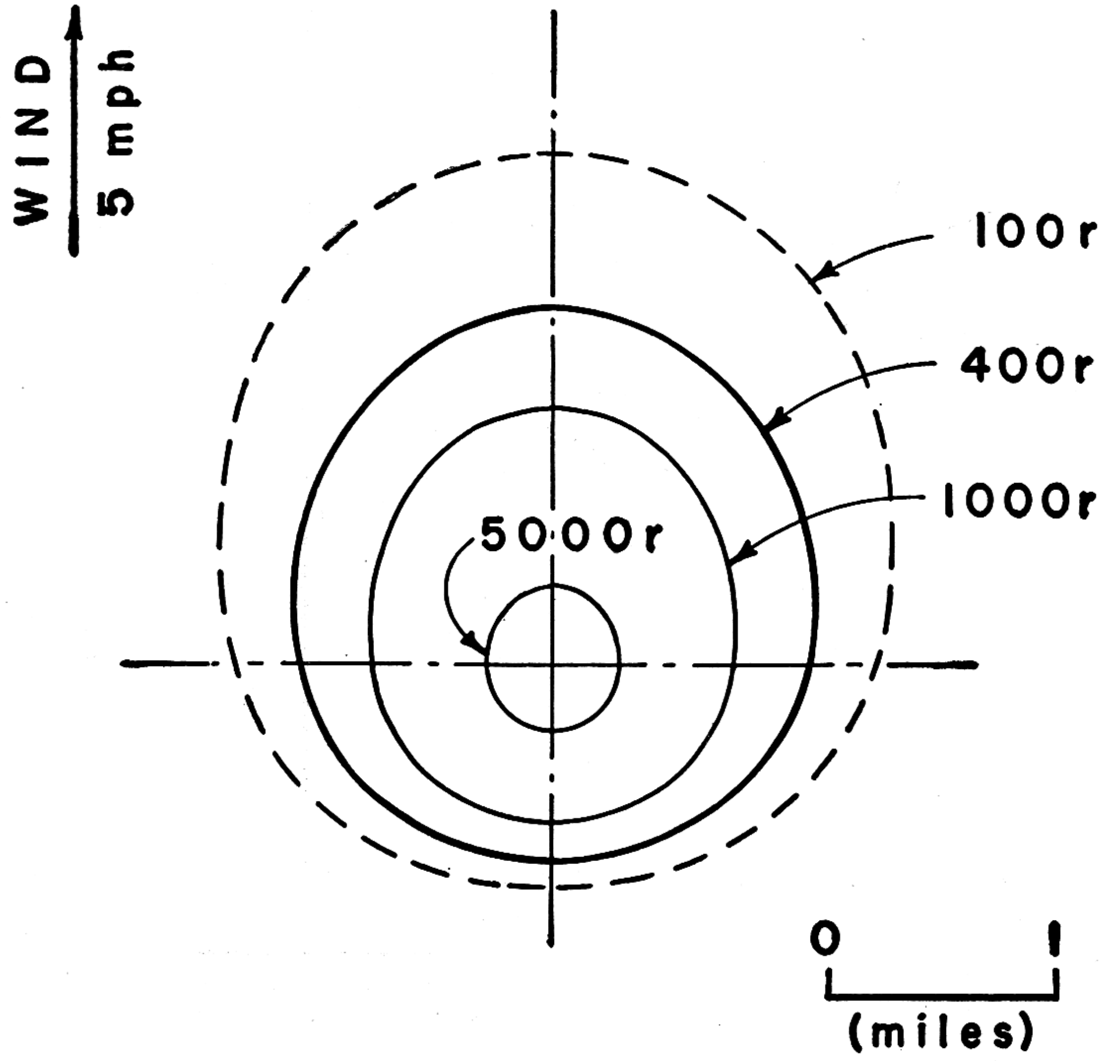


Figure 8.91a. Contours for various integrated radiation dosages due to base surge from underwater burst.

b, and c. The dosage due to the base surge mist as it passes over and through an area is shown in Fig. 8.91a. The distortion from symmetry is due to the fact that a wind of about 5 miles per hour was blowing at and near the surface of the lagoon at the time of the detonation. This results, of course, in the radioactive contamination extending much further downwind than in the upwind direction.[19]

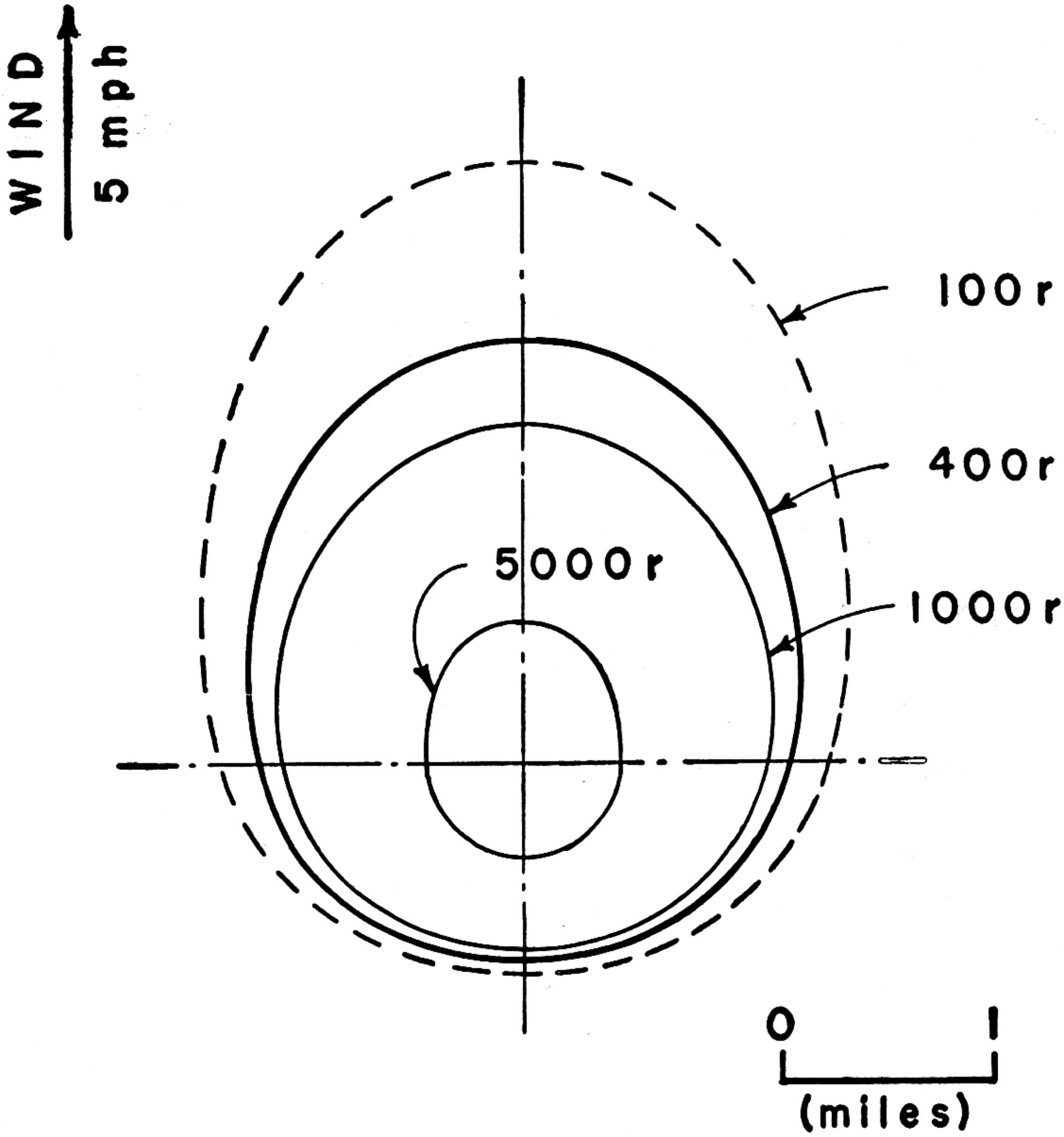


Figure 8.91b. Contours for various integrated radiation dosages due to contamination from underwater burst.

8.92 The integrated dosage contours resulting from contamination due to rain from both the base surge and the fall-out from the atomic cloud, are given in Fig. 8.91b, while Fig. 8.91c indicates the contours for total dosage, i. e., the sum of the base surge and contamination dosages. It is probable that the data in Fig. 8.91b, and hence also in Fig. 8.91c, represent an underestimate, because a proportion of the contaminated water falling as rain ran off the decks of

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[19] For the effect of wind on the area, etc., of the base surge, see § 4.79.

the ships and back into the lagoon, so that its activity was not included in the measured dosage.

8.93 It may be mentioned that the radioactive mist of the base surge is most hazardous within the first few minutes of its formation.

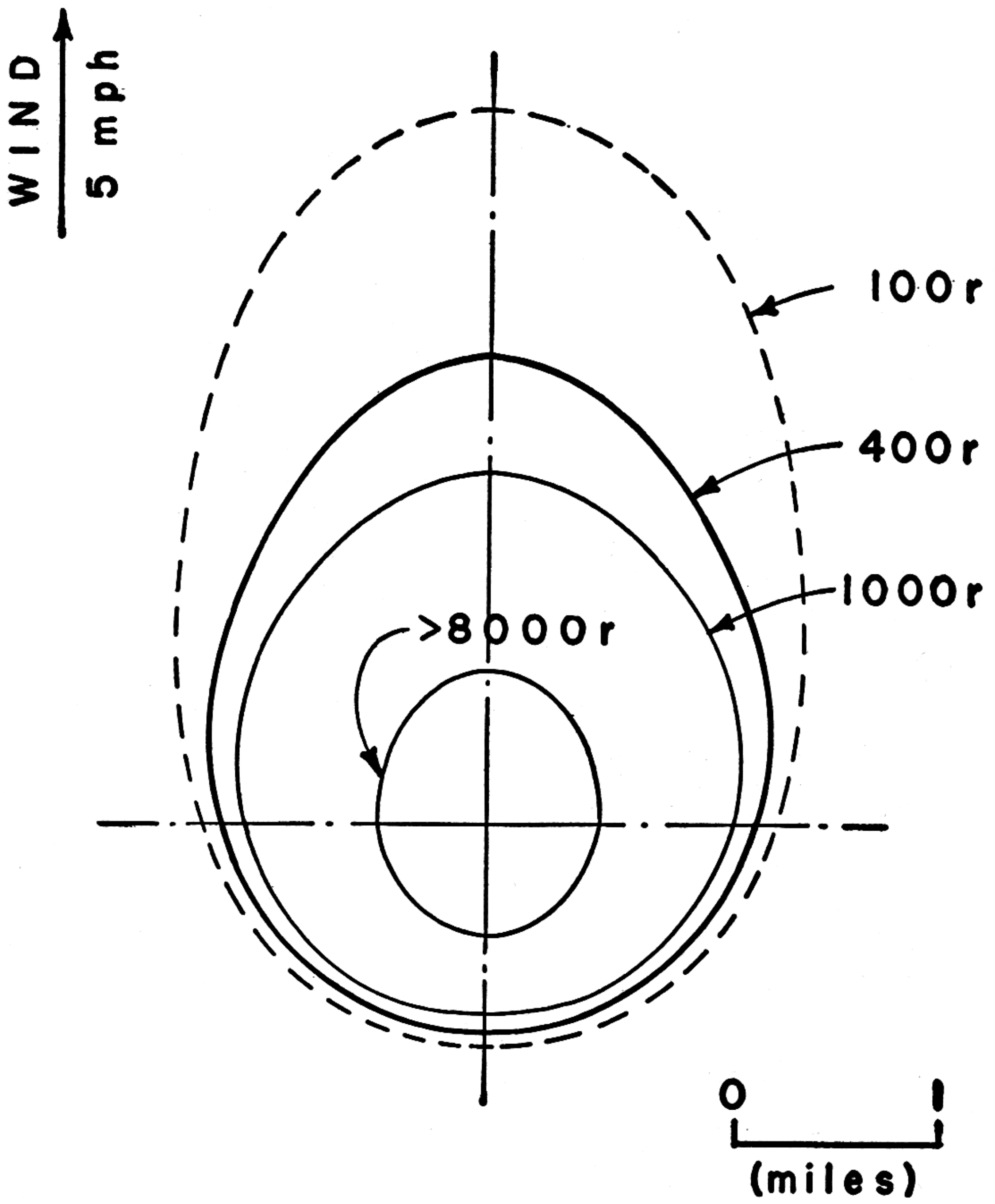

Figure 8.91c. Contours for total dosage due to base surge and contamination from underwater burst.

Its activity decreases rapidly in the course of a short time due to the operation of three factors, namely, dilution by increase of volume as a result of mixing with air, raining out of the active material as the droplets increase in size, and natural radioactive decay. Calculations which probably give a correct order of magnitude, at least, indicate that the dosage rate within the base surge decreases by a factor of about 400 in the interval between 1 and 4 minutes after the underwater burst. This rapid decrease indicates the advantage of protection from the base surge mist during the 3 or 4 minutes immediately following an atomic explosion. At Bikini, contamination of the interior of the ships, due to the base surge, was minimized by closing down the hatches and stopping the ventilating systems. Attention to this point, especially in the early stages, would obviously prove well worth while.

RADIOACTIVITY OF WATER

8.94 It was recorded earlier that in an underwater burst of an atomic bomb most of the radioactivity of the fission products ultimately appears in the water. Because of the large volume in which these substances are dispersed, the activity in the water is not as high as might be feared, except close to the explosion center and within a short time of the burst. As a result of diffusion of the active material, mixing with water from outside the contaminated area, and natural decay of the radioactivity, the dosage decreases with fair rapidity in a short time. In Table 8.94 are given the area and mean diameter of the contaminated portion of the lagoon after the Bikini "Baker" test, together with maximum observed dosage rates at various times after the burst.

TABLE 8.94

DIMENSIONS AND MAXIMUM DOSAGE RATE OF CONTAMINATED WATER IN BIKINI LAGOON

Time after explosion (hours)	*Contaminated area (square miles)*	*Mean diameter (miles)*	*Maximum dosage rate (r per day)*
4	16. 6	4. 6	75
38	18. 4	4. 8	10
62	48. 6	7. 9	5
86	61. 8	8. 9	1
100	70. 6	9. 5	. 6
130	107	11. 7	. 2
200	160	14. 3	. 01

8.95. It is evident that, although a ship would not wish to remain in the contaminated area for any length of time soon after the explosion, passage across the water would not be a great hazard. It is to be understood, of course, that condensers and evaporators would have to be closed down while the ship is in contaminated waters. Further, because of the decrease in activity with time, it seems unlikely that an underwater burst of an atomic bomb would prevent operation of a harbor for any length of time, at least as far as contamination of the water is concerned. However, it should be borne in mind that the results in Table 8.94, although probably fairly representative, would be affected by the geophysical conditions of the harbor.

8.96 Another factor which contributed to the loss in activity of the water at Bikini was settling of the fission products to the bottom of the lagoon. To judge from samples of bottom material collected 7 and 16 days after the explosion, a considerable proportion of the active material must have been ultimately removed in this manner. The results indicate that the major deposition had occurred within a week and that it covered an area of over 60 square miles. On the assumption that the fission products had penetrated to a depth of 1 foot, it can be estimated that the total mass of the bottom material, in which the radioactivity was distributed, was about 1.4×10^8 tons. Consequently, even though the total initial activity of the fission products was high, about 2×10^6 curies measured a week after the explosion, its wide distribution at the bottom of the lagoon would mean that it did not represent a great hazard to marine life. Observations made several months after the explosion indicated, too, that there was no tendency for the contaminated material to spread.

8.97 It is of interest in this connection to calculate the amount of radiation due to the radioactive isotope of potassium, mass number 40, in sea water. This isotope is present to the extent of 0.012 percent in all forms of potassium, regardless of its source. It emits a beta particle, with a maximum energy of 1.3 Mev, and a gamma photon of 1.5-Mev energy. Because of its long half life, about 1.5×10^9 years, the activity is normally of little significance, although it makes an appreciable contribution to the total background radioactivity of the body (§ 8.49). Since sea water contains 0.4 gram of potassium per liter, the total weight of radiopotassium 40 in the Bikini lagoon is estimated to be 1.4×10^9 grams or 2.1×10^{31} atoms. From the known half life it can be calculated that there will be a total of about 4×10^{14} disintegrations per second, which is equivalent to 10^4 curies of activity due to the potassium 40 alone. In other words, the normal background activity of Bikini lagoon, before the atomic bomb explosion, was at least 10^4 curies. This is not very different from the fission product activity collected at the bottom about 18 months after the detonation.

8.98. There is a possibility that after an underwater burst of an atomic bomb, the radioactivity might be spread over a large area due to the action of marine life. It is well known that land plants absorb and so concentrate mineral elements from the soil and that these are further concentrated in animals feeding on the plants. Similar circumstances arise in water environments; the simple plants, i. e., phytoplankton and algae, absorb the nutritive salts from the water, and they are then accumulated in the larger aquatic forms, e. g., fish, which directly or indirectly consume the simple plants.

8.99 In water containing radioactive materials, the latter are concentrated by the fish in the same manner and for the same length of time as are the stable forms of the corresponding elements. If the fish die, the radioactive isotopes are not lost, but they return to the water, as do the stable isotopes, to take part once again in the life cycle. Because of the landlocked nature of the Bikini lagoon, there is evidently little or no outward migration of the larger aquatic organisms so that, as mentioned above, there is no appreciable tendency for the radioactivity to spread. However, due to the behavior of the anadromous migratory fishes, e. g., salmon, shad, etc., which feed in the sea and then migrate upstream to die, or of birds that concentrate the minerals of the sea in guano, there might be some distribution of radioactivity in other cases following an underwater atomic explosion. The extent of such dispersion and its effects would depend greatly on circumstances and appears difficult to estimate.

RADIOACTIVE CONTAMINATION OF LAND AREAS

8.100 The underwater burst at Bikini took place far enough from shore to prevent any appreciable contamination of land areas. Some radioactive rain fell at large distances from the explosion center (§ 2.36), but the activity was not serious. The possibility must be considered, however, of an underwater atomic explosion so near to the shore that significant amounts of the fall-out and the base surge will reach the adjacent land areas, and possibly affect dock facilities, warehouses, etc. As indicated earlier, because some of the radioactively contaminated water ran off the ships at Bikini, the values in Figs. 8.91b and 8.91c may represent an underestimate if applied to the shore. However, there may be compensating factors in the deposition of active material on the roofs or protruding portions of buildings, and also because of the shielding effects of various structures.

8.101 A rough attempt to assess the contamination, in terms of radiation dosage rates, of adjacent land areas from the underwater burst of a nominal atomic bomb, at 1 hour after the explosion is made in Fig. 8.101. The results are based on the assumption that the activity is due to fission products with a mean gamma-ray energy of 0.7 Mev (§ 8.11). Four contour lines are shown, representing radiation dosage rates of 400, 50, 10, and almost zero roentgens per hour, respectively. In the region outside the last contour line, the danger due to radioactivity may, in general, although probably not always, be ignored. It should be noted that the results are based on the assumption that a 5-mile-per-hour wind is blowing, as was the case at Bikini. A difference in the wind velocity or a change in the direction or velocity within a short time after the explosion would, of course, alter the picture appreciably.

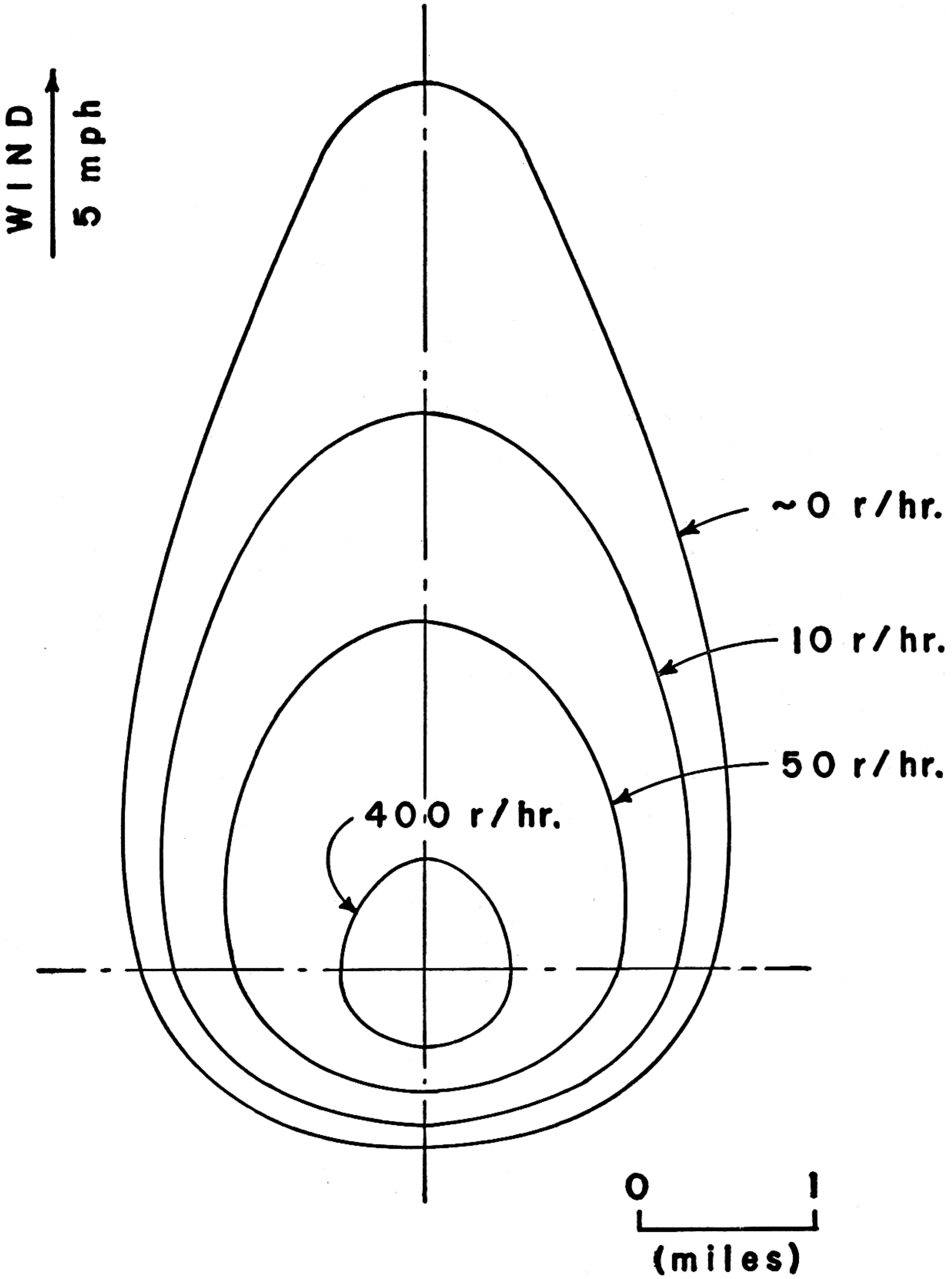

Figure 8.101. Radiation dosage rate contours at 1 hour after explosion due to fission products from underwater burst.

CHAPTER X

DECONTAMINATION[1]

A. INTRODUCTION

TREATMENT OF CONTAMINATED MATERIAL

10.1 It was seen in Chapter VIII that radioactive contamination may be caused by the fission products formed in the detonation of an atomic bomb, by neutron-induced activity in soil and water, and by the deliberate use of specific radioisotopes, apart from their association with the bomb, as radiological warfare agents. These sources would be largely responsible for external contamination. In addition, there is the possibility that plutonium which has escaped fission may act as a contaminant representing an internal hazard. It is now necessary to examine the problem of dealing with various objects which have become contaminated, in one way or another.

10.2 There are essentially three ways whereby the hazard associated with radioactive contamination may be minimized: first, to dispose completely of the material by deep burial in the ground or at sea; second, to keep it at a distance for a sufficient time to permit the radioactivity to decay to a reasonably safe level; and third, to attempt to remove the contaminant, that is, to decontaminate the material. These three procedures were used, in one way or another, in connection with radioactive contamination suffered by ships and their equipment after the Bikini "Baker" test.

10.3 The particular method that is adopted in any case will depend on circumstances. Large structures could not easily be disposed of, and decontamination could be attempted after the activity had decayed to some extent. With smaller structures, decontamination might prove too costly if the activity is high, so that burial is the most economical plan. If the radioactive contamination were not too great, however, decontamination could be attempted almost immediately. On the other hand, in certain instances, it might prove more advantageous simply to set the article aside for the activity to decay.

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[1] Material contributed by E. S. Gilfillan, S. Glasstone, C. R. Schwob, W. E. Strope, W. H Sullivan.

10.4 At Bikini the U. S. S. *Independence*, a small aircraft carrier, received such a large radiation dosage that had there been any personnel on the hangar deck at the time they would have succumbed from external radiation, apart from the effects of blast. Yet 2 weeks after the detonation the dosage rate was about 3 r per day, permitting short time access. About a year later, the average dosage rate was only 0.3 r per day, and 3 years after the original contamination the *Independence* was in use at the San Francisco Naval Shipyard, where she housed the experimental engineering group of the Naval Radiological Defense Laboratory. It was difficult at that time to find any areas on the ship where the radiation dosage would have exceeded the limit of 0.3 r per week adopted in installations of the Atomic Energy Commission (§ 8.4).

10.5 It should be noted that no decontamination of the *Independence* was attempted, primarily because the vessel was in a battered condition (see Fig. 5.79a), and it seemed unlikely that she could be returned to service as an aircraft carrier. However, some of the other vessels at Bikini were decontaminated and reclaimed much sooner. Two submarines, thus decontaminated (Fig. 10.5), were used soon afterward in the Naval Reserve, with no risk to the operating personnel. Most of the other target vessels were destroyed, not because decontamination was not feasible, but mainly because they were damaged in other ways and decontamination would not have been economical.

10.6 Except where radioactive solutions, such as were present after the underwater burst at Bikini, soak into porous materials, like rope, textiles, unpainted or unvarnished wood, etc., or where neutrons have penetrated and induced activity to some depth, the decontamination will be largely restricted to the surfaces of materials, objects, and structures. An outstanding exception would, of course, be the radioactive contamination of water supplies for drinking purposes. The problem of decontamination is thus, to a considerable degree, a problem of removing sufficient of the surface material to reduce the activity to the extent that it is no longer a hazard. The methods of surface removal may be divided into two main categories, namely, chemical and physical. In the first case, the contamination is eliminated by making use of chemical reagents which, if sufficiently mild, will have a minor effect on the underlying material. But in the second case, an appreciable thickness of the actual surface is removed.

10.7 It should be understood that the activity of a particular radioisotope is not changed in any way by chemical reaction. All the latter can do is to convert the active isotope into a soluble compound, so that it can be detached and washed off as a solution. Certain processes of decontamination, involving the use of detergents, represent a category intermediate between chemical and physical.

Figure 10.5. Submarine U. S. S. *Skate*, damaged and radioactive after the Bikini "Able" explosion.

B. NATURE OF RADIOACTIVE CONTAMINATION

Identification of Contaminants

10.8 In order to devise suitable chemical decontamination procedures, it is necessary to know something of the nature of the radioactive material responsible for the contamination. The composition of the fission products at various times after the atomic explosion is fairly well known, as will be seen below. Consequently, if it is certain that the contamination is due to fission products, then appropriate chemical methods of treatment could be developed. A

TABLE 10.15

MOST RADIOACTIVE CONSTITUENTS OF PRODUCTS AT VARIOUS TIMES AFTER FISSION

1 hour	*1 day*	*1 week*	*1 month*	*6 months–1 year*
Rare Earths*	Rare Earths	Rare Earths	Rare Earths	Rare Earths
Tellurium	Iodine	Iodine	Barium	Columbium
Barium	Zirconium	Tellurium	Zirconium	Zirconium
Iodine	Columbium	Barium	Strontium	Strontium
Rubidium	Xenon	Molybdenum	Ruthenium	Ruthenium
Krypton	Strontium	Xenon	Rhodium	Rhodium
Strontium	Molybdenum	Zirconium	Columbium	Barium
Xenon	Tellurium	Strontium	Iodine	
Molybdenum	Rhodium	Ruthenium	Xenon	

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* Because of its chemical similarity, yttrium has been included with the rare-earth elements in every case.

Because of their similarity in chemical properties, the rare-earth elements and yttrium have been grouped together. The various elements are arranged in order of their decreasing contribution to the total activity.

10.16 It is an interesting and important fact that from an hour to a year, and probably longer, after fission has taken place, at least 30 percent of the fission-product activity is due to radioisotopes of the rare-earth elements and yttrium. The removal of these elements alone would thus reduce the degree of contamination by about a third or more. This has been achieved by the use of various substances which form soluble complex ions with the rare-earth elements (cf. § 10.51).

10.17 Any substance capable of forming complex ions in this manner is frequently referred to as a *complexing agent.* While salts of citric acid and other organic acids are perhaps the most important such agents in general use for decontamination purposes, it is possible that a concentrated solution of a chloride might prove to be a complexing agent for ruthenium and rhodium, and perhaps for some other important fission products.

10.18 Since one of the objects of decontamination is to prevent internal absorption of radioactive materials, brief mention may be made here of the hazards due to the ingestion of certain fission products. The subject will, however, be considered more fully in Chapter XI. Some elements, particularly iodine, strontium, barium, zirconium, and cerium, are strongly held in the body so that their consequences, when absorbed as radioisotopes, may be more serious removal of the film will facilitate the action of the various agents used for more thorough decontamination.

10.34. In every attempt at decontamination, preliminary or final, the safety of personnel is an essential consideration. The immediate emergency measures must consequently be delayed, as stated above, until the activity has decayed sufficiently to permit operation without excessive risk. Those directly employed in the decontaminating work should wear suitable protective clothing, of rubber if necessary, and should be provided with rubber boots and gloves. If spray or dust is produced in the operation goggles, and masks must be worn (cf. § 12.79 *et seq.*).

10.35 Shielding, whether by distance, terrain, walls, structures, etc., must be used as advantageously as possible. For example, the decontamination of a building or a ship should be started from a suitable position in the interior, where the activity will probably be less than on the outside. In this connection it is recommended that installations of strategic importance, in a situation where contamination is a possibility, should be provided with hosing down equipment controllable from the interior.

10.36 It is not possible to give a general rule concerning the areas from which decontamination should be initiated. In some cases it would be advantageous to start in a region where the activity is low, for this will not only make the operation less hazardous but will allow time for decay of the more highly contaminated portions. On the other hand, in certain circumstances, it might be advisable first to carry out a quick, even if preliminary, decontamination of an area of high contamination in order to permit freedom of movement.

SURFACE REMOVAL

10.37 The problems of thorough decontamination are so involved and so novel that a great deal of work will be necessary before the most effective procedures are developed. The information given here, based on limited experience, is the best available at the present time. But improved methods for the treatment of materials, structures, etc., which have become contaminated with radioactivity, will undoubtedly be developed in due course. At present, although certain general principles are apparent, it seems impossible to make predictions concerning the efficiency of a particular decontamination procedure in any given circumstances. It would be necessary, therefore, in actual practice, to use a succession of methods until the desired degree of decontamination is achieved.

10.38 For nonabsorptive substances, removal of the entire surface of the material is an obvious means of securing decontamination. While it cannot be applied to all surfaces, it is highly successful whenever it is feasible, except perhaps where capture of neutrons has induced activity at some distance below the surface. In this, as in all decontamination procedures, it is necessary to exercise rigid control over the radioactive residues. They must not be allowed to recontaminate newly exposed or adjacent surfaces, nor must they be permitted to become an inhalation or ingestion hazard in the form of dust. During an operation, these requirements can be met by wetting down the surfaces with water or with solutions of certain chemicals which dissolve the solid particles, as mentioned below.

10.39 Physical methods of surface removal are often difficult because they involve much labor and sometimes special equipment. Methods employing abrasion are perhaps the most effective; wet sandblasting, for example, was used successfully in decontaminating large areas of the Bikini target vessels (Fig. 10.39). The techniques

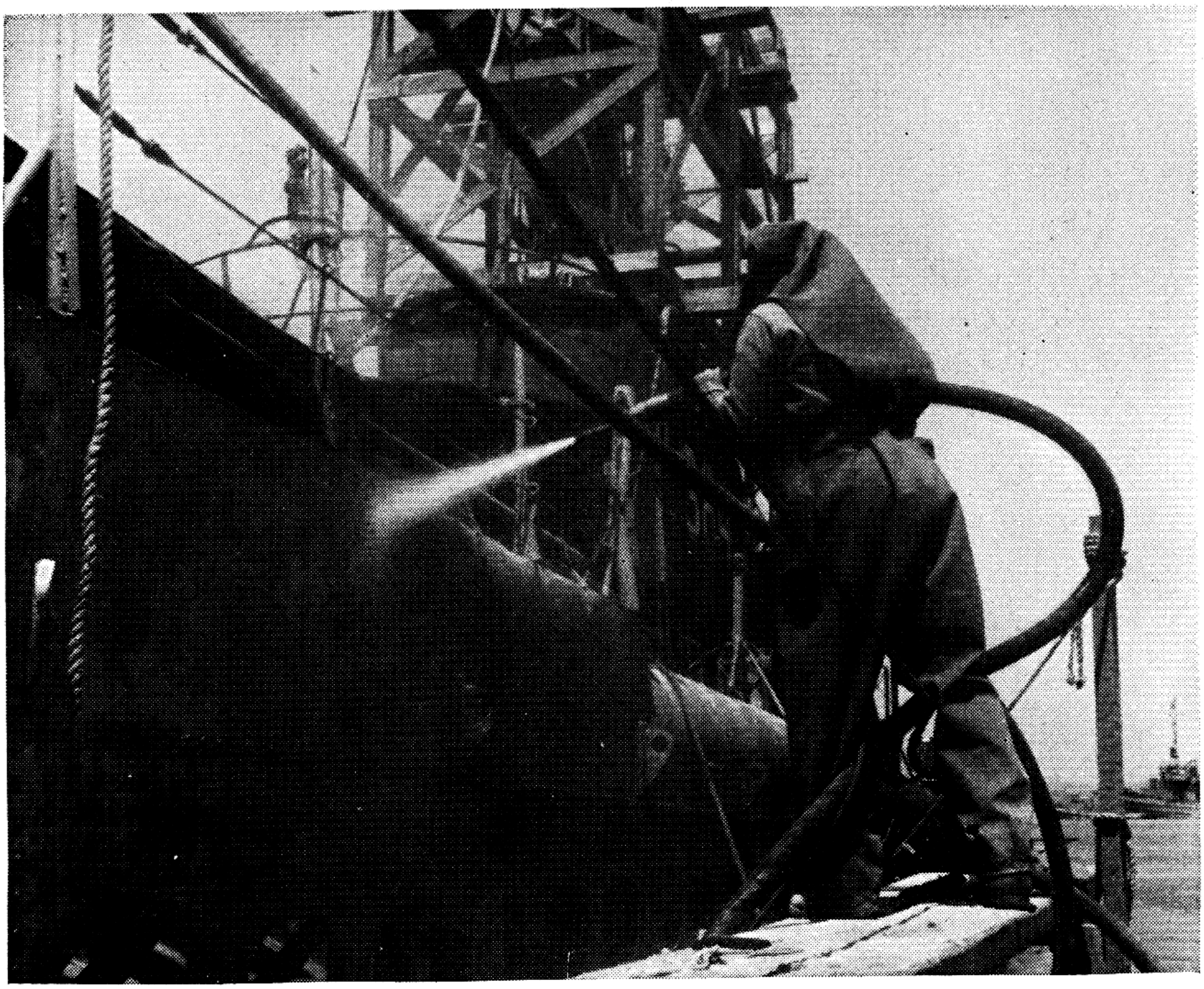

Figure 10.39. Wet sandblasting for removal of radioactive contamination. (Note protective clothing worn by the operator.)

involved here are a part of normal ship maintenance, and the equipment and trained personnel are generally available at military and industrial establishments. The wet sandblasting method can also be employed for the decontamination of unprotected concrete. This procedure leaves large volumes of sand and water, containing the active material, and although their disposal may present a problem, the fact that the contaminant is thereby considerably diluted is some compensation.

10.40 Abrasives less radical than sand, and which effect removal of only a thin surface layer, have also been used. Soft materials like sawdust and other substances of a similar nature, have been suggested for the decontamination of delicate articles, such as instruments or bearing surfaces, that would be injured by sand. Similarly, scrubbing may be used for the removal of a thin outer layer. Steel wool, wire brushes, floor polishers, or various buffing or polishing machines, can be adapted to decontamination by surface removal in various circumstances.

10.41 Chemical means can also be applied to remove the surface, and with it the contaminating radioactivity. The action is rapid and certain, and in some instances it is the only practical method. The use of highly corrosive or other dangerous chemicals, although they might be effective, should be avoided if possible. The substances employed must be capable of being stored without danger, available in large quantities, and preferably of small bulk. Because of these requirements, primary consideration must be given to the use of aqueous solutions. Organic solvents are usually inflammable or toxic, or both, but most water-soluble chemicals can be stored easily, and dissolved quickly when desired. The heat evolved when some materials, such as caustic soda, are dissolved is often advantageous in that it hastens chemical action. Further, standard fire-fighting equipment, pumps, transport and mixing devices are particularly adapted to the handling of aqueous solutions.

10.42 Decontamination by chemical means usually results in the transfer of the activity to fairly large volumes of liquid, thereby presenting a disposal problem. Mere wetting of the surface by the solution of the chemical reagent is nearly as efficient as flooding for decontamination. If wetting only is used, the waste material can be confined and is controllable, but it will have a relatively high activity. On the other hand, with the flooding method the resulting solution is more dilute and the radioactivity is dispersed in a larger volume. Both procedures have advantages and disadvantages, and the particular method used must be determined by the circumstances.

10.43 Chemical methods of surface removal can be designed for each specific type of surface. For example, alkalis have been found to be effective in removing contaminated layers of paint. In special cases, drastic treatments using acids, caustic alkalis, and other corrosive agents have proved successful in removing surfaces, but they are liable to be destructive, since they erode and pit the base material while removing the surface. Mild chemical means of surface removal, such as by the use of complexing agents, which will be mentioned below, have been employed in certain cases, for example, for paint containing titanium.

10.44 A combination of physical and chemical treatments is represented by live steam as a decontaminating agent, especially in conjunction with a detergent, as mentioned in § 10.33. It has been found particularly valuable for cleaning up highly contaminated areas in laboratories and plants. It appears to be especially efficient for painted surfaces, the action being based on the partial destruction of the paint by hydrolysis. In addition, loose or mechanically held contamination is swept away, and the surface suffers some disintegration because of the sudden increase of temperature. It is probable that the combination of live steam with a detergent may prove useful in decontaminating many types of surfaces and objects.

10.45 Heat by itself acts in a manner similar to live steam. The contact of a blow-torch flame with a contaminated paint surface for a fraction of a second produces a marked reduction in activity. This method of decontamination should not be attempted unless adequate ventilation is available for removal of the radioactive fumes.

REMOVAL OF LIGHTLY HELD MATERIAL

10.46 In the examination of the naval vessels which had become contaminated with radioactivity at Bikini, it was observed that much of the activity was associated with dust, corroded areas, etc., which could be removed without difficulty. In some circumstances, up to 90 percent of the radioactivity remaining on ship surfaces three years after being contaminated was removable by vacuum sweeping or brushing.

10.47 In the event of contamination due to radioactively contaminated water, following an underwater burst of an atomic bomb, water under high pressure can be used for removing loosely held contaminants (Fig. 10.47). However, there is some evidence that radioactive dusts, such as might be produced from an underground burst or dry fall-out or might be used in radiological warfare, tend to become attached to surfaces as a result of treatment with water or an aqueous solution. In such instances, dry physical methods, e. g., vacuum cleaning, brushing, application of adhesive, etc., are preferred as an initial step to prevent spread or strong attachment of the contamination.

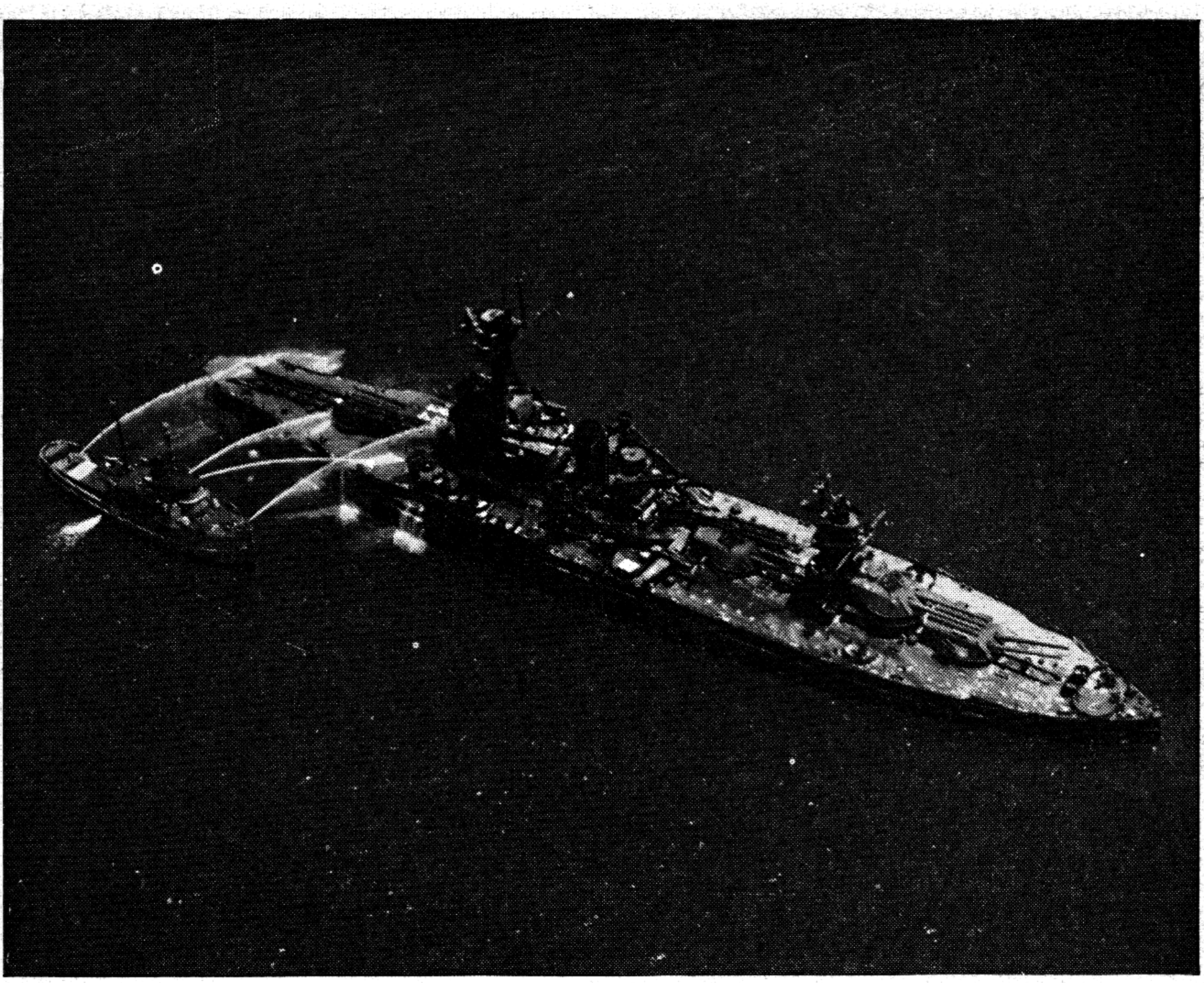

Figure 10.47. Preliminary decontamination of U. S. S. *New York* after the "Baker" test at Bikini; the decks are being washed down with sea water by a Navy fireboat.

10.48 Adhesives of various kinds have been found practical for removing loose dust and mechanically held contamination. An adhesive coating is applied to the contaminated surface, and is then stripped off; some of the radioactive material will be retained by the coating when it is removed. Sprayed strippable coatings, which can penetrate pores and crevices, are useful for decontaminating moderately rough surfaces. For smooth surfaces, adhesive tapes of different kinds have proved successful. Several types of putty have been tried, but the results have not been satisfactory.

10.49 In dealing with loosely held contamination, the obvious use of soap and water cannot be neglected. As indicated previously, not only will soap and other detergents remove dirt, dust, grease, etc., which has become radioactively contaminated, but it is safe for most surfaces, nonhazardous, and does not call for particular experience in its application. As will be seen later, detergents and wetting agents have other valuable properties in decontamination.

REMOVAL OF TIGHTLY HELD MATERIALS

10.50 When the extent of decontamination resulting from the removal of lightly held radioactive material is not sufficient, further treatment will be necessary. Surface removal, as described above, may be employed, but the procedures are necessarily harsh and unsuitable for delicate equipment; further, after decontamination, the surface must frequently be renewed to provide protection against corrosion. The roughened surface is also liable to be more susceptible to subsequent contamination. The use of chemical methods can frequently avoid these disadvantages. By means of a solution of a chemical reagent, it may be possible to transfer the radioactivity to a liquid phase which is then washed off. In this connection three general principles have been employed; they are formation of soluble complexes, ion exchange, and solubilization.

10.51 Substances which have a greater affinity for the decontaminating element than for the surface, and which form water-soluble compounds with it, are suitable complexing or sequestering agents. Much research has been conducted with the object of finding compounds or ions which form complexes with the fission products and with the fissionable material constituting the atomic explosive. Sodium citrate solutions were used with some success in the clean-up operations after the Bikini tests, but other substances, such as the sodium salts of ethylenediamine-tetracetic acid, aminotriacetic acid, and pyrophosphoric acid, have been found to be more satisfactory and generally cheaper. It is of interest to mention that, contrary to theoretical expectation, strongly acidified citric acid solutions were more effective than neutral citrate in removing radioactive contamination. Apparently, the hydrochloric acid present dissolved rust and scale in which the contaminants tended to concentrate, and which were consequently difficult to decontaminate. Much research still remains to be done before a reliable complexing agent or a simple mixture of such agents can be recommended for general use.

10.52 The partial removal of radioactive ions from surfaces is rendered possible by application of the principle of chemical equilibrium. The undesirable ions of a radioisotope may exchange with ions of nonradioactive isotopes of the same element applied in solution. The exchange will result in a decrease in the number of radioactive ions on the surface, even though the total number of ions, radioactive and stable, may actually increase. For decontamination due to fission products from an atomic explosion, this procedure would require, theoretically, 34 elements in a variety of valence forms. Some of these are prohibitively rare, while others, namely, technetium (atomic number 43) and promethium (atomic number 61), do not exist in nonradioactive forms. Possibly certain common ions of high valence, such as aluminum, iron, or cerium, may prove useful in this connection. Unfortunately, the exchange reactions are very slow, and laboratory results obtained so far have not been too encouraging.

10.53 Insoluble contaminants, such as oxides, basic salts, etc., may not furnish enough ions to permit rapid complexing or exchange action. However, some of these will respond to the action of wetting agents and detergents. The peptizing properties of these substances allows the particles of insoluble material to be washed away as a suspension. The use of a detergent in any decontamination procedure is beneficial because, in addition to the so-called solubilizing effect just mentioned, it promotes more complete and rapid wetting of the surface, as well as facilitating, as noted earlier, removal of dust, dirt, etc., carrying radioactive material.

10.54 In considering the problem of decontamination, there is one fundamental point which must not be forgotten. Decontamination procedures do not neutralize the radioactivity; they merely transfer the active material from one place to another. Consequently, before undertaking decontamination it is necessary to arrange for the proper disposal of the material removed, to a location where it does not represent a hazard. The method to be used must be determined by the circumstances existing at the time.

City and Domestic Decontamination

10.55 In the event of serious radioactive contamination of a large part of a city, steps would have to be taken to make it habitable within a reasonable time. The most important matter in this connection would appear to be the removal or coverage of loose material which might form dust that would be inhaled or ingested with food. For paved streets flushing, perhaps with the aid of detergents, street cleaning or vacuum sweeping, if feasible, might be the first steps. If the contaminant is on the surface or has not penetrated too deeply, concrete, stone and brick buildings would perhaps have to be wet-sandblasted and reroofed. Painted wooden structures might be decontaminated by some of the methods given earlier in this chapter, but stucco buildings might have to be removed. The same could well apply to roofs, which would collect considerable amounts of radioactive material, but could not be easily decontaminated.

10.56 Soils have a fairly high specific surface and also have well-defined base exchange properties; as a result they will tend to concentrate radioactive material. This is fortunate, in a sense, because in the washing down of contaminated streets, buildings, etc., much of the water will be transferred to the surrounding soil, if special drainage facilities are not available. Because of the properties mentioned above, the radioactivity will remain in the uppermost few inches. The only scheme that seems to be practical for dealing with such topsoil, as well as that from parks and lawns in the contaminated city, is to remove it or to cover it with at least a foot of fresh soil. This could perhaps be done by turning the soil over, so that the lower uncontaminated soil covered that which had become contaminated. In any operations with such soil, standard wetting-down procedures would be required to minimize the hazard due to radioactive dust.

10.57 Badly contaminated clothing, as well as rugs, curtains, and upholstered furniture would have to be discarded and buried or burned in proper incinerators perhaps designed to prevent the escape of radioactive smoke. If the contamination is not too serious, laundering may be effective in reducing the activity sufficiently to permit reuse. In most cases, it is probable that interior walls and floors of houses and buildings, if still surviving after an atomic explosion, could be decontaminated by thorough washing. They could then be repainted, papered, or varnished according to circumstances.

Decontamination of Food and Water

10.58 Properly covered foods should undergo little or no contamination. The same will be true of canned goods or any materials in impervious, dustproof wrappings. There appears to be no feasible means for salvaging unprotected food, either in the home, the store or in the fields, which has become radioactively contaminated.

10.59 The contamination of water supplies might arise in several ways, such as fall-out particles dropping into a river or reservoir, accumulation of radioactivity from fall-out particles deposited on the watershed, explosion of an atomic bomb in or near a reservoir, or the deliberate use of radioisotopes in radiological warfare. If the degree of contamination is not too severe, then it is probable that, as a result of the operation of several factors, e. g., dilution by flow, natural decay, adsorption, etc., the water will not usually be rendered unfit for consumption, except perhaps for a limited time immediately following the contamination.

10.60 In surface waters, radioactive contaminants will tend to be adsorbed by the suspended and colloidal matter that is invariably present. This matter will partly settle or be adsorbed by the walls and bottom of the reservoir. In urban water systems radioactive material escaping adsorption in the reservoir itself may be picked up by the surfaces of the distribution system which usually consist of highly adsorbent brick or rusted iron. When, in addition, the purification process includes coagulation, sedimentation and filtration stages, it is expected that very little radioactive material will normally reach the consumer.

10.61 Because of the adsorptive properties of soil, referred to above, underground sources of water are generally safe from contamination. For the same reason, moderately deep wells, even under contaminated ground, can be used as sources of drinking water, provided surface drainage of contaminated material is prevented.

10.62 If a reservoir or river is seriously contaminated, and the water is not subjected to coagulation or filtration, as described above, the water may be unfit for consumption for several days. However, because of dilution and natural decay of the radioactivity, the degree of contamination will decrease with time. It would be necessary, in cases of this kind, to subject the water to careful examination for radioactivity and to withhold the supply until it is reasonably safe for human consumption. It should be remembered in this connection that since the water is taken internally, alpha and beta activity, as well as gamma activity, is important.

10.63 In some cities water is taken directly from a river and merely chlorinated before being supplied for domestic consumption. If no alternative source of water is available in case of emergency, consideration should be given to the provision of cationic and anionic exchange columns or beds to be used if the regular supply should become contaminated. Home water softeners might serve the same purpose. In hospitals and on ships sufficient water for emergency purposes could be obtained by distillation. It was found at Bikini, for example, that contaminated water when distilled was perfectly safe for drinking purposes; the radioactive material remained behind in the residual scale and brine. It should be emphasized, however, that mere boiling of water contaminated with radioactivity is of no value.

10.64 The suggestion has been made that algae and zoogleal bacteria, such as are used in the activated sludge process for purification of sewage, which absorb and concentrate mineral elements directly from water (cf. § 8.98), could be employed to remove radioactive contamination from reservoirs. In order to be effective, the conditions would have to be such as to cause profuse growth of the organisms. Once the activity is incorporated into the latter, the water could be drawn off, and the bacteria, etc., removed by mechanical filtration or by sludge beds and allowed to decay. Whether this procedure will prove practical on a large scale is not yet known, although preliminary experiments indicate some success in the removal of plutonium from contaminated water.

10.65 The accepted safe tolerance level for water containing fission products is 4×10^{-6} microcurie/cc. Assuming the mean gamma-ray energy to be 0.7 Mev (§ 8.11), it can be shown by means of Fig. 8.37b that the dosage rate measured just above the surface of a body of water contaminated to this extent would be nearly 4×10^{-6} r per hour. This activity in curies is appreciably lower than that of some radioactive mineral waters which are consumed in quantity without obvious deleterious consequences. It would appear, therefore, that in an emergency, water with many times the accepted tolerance limit could be used for drinking in limited amounts. Because of the rapid decay of the fission products with time, the activity of the water and the corresponding hazard, if any, would soon decrease.[4]

SPECIAL PROTECTIVE METHODS

10.66 The ideal defense against radioactive contamination is to use, wherever possible, surfaces which are either resistant to such contamination or from which the active material can be readily removed. It has been found, for example, that surfaces coated with certain plastic paints are relatively easily decontaminated. Attempts are being made to classify materials according to their contamination and decontamination characteristics, but it will be some time before a clear understanding of the subject can be obtained. In a general way, however, it can be stated that an ideal surface for the purpose in mind should have its specific surface area, i. e., area per unit mass, porosity, and chemical and surface activity as small as possible. There are indications at present that certain materials, such as polyethylene,

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[4] The presence in a reservoir of appreciable amounts of plutonium, with its long half life and tendency to concentrate in the body (§ 11.93), would present a special problem. For the accepted tolerance level of plutonium in water, see § 12.72.

have these desirable properties, and these substances could be used to form thin surface layers on various articles or equipment.

10.67 Structural materials, e. g., concrete, brick, and soft woods, present a special problem, since decontamination of porous substances is virtually impossible. At the present time, it appears that well-maintained paint or other sealer is the only means of protection against radioactive contamination. This matter should be borne in mind, especially in connection with new construction near bodies of water where an underwater explosion is a possibility. In designing structures, efforts should be made to eliminate inaccessible spaces, sharp concavities, and poor drainage.

10.68 Another possibility in connection with protection against radioactive contamination, which has been found successful in laboratories handling high levels of activity, is to use strippable coatings. A removable protection of this kind, consisting of adhesive tape or special sprayed or brushed coatings of a plastic material, is affixed directly to the surface to be protected. In the event of radioactive contamination, the plastic surface is stripped off and replaced with a new one.

10.69 Where the foregoing procedures are not possible, vital equipment may be kept under cover, by means of tarpaulins or other movable protection. Emergency access ways to installations should be protected in some manner, for experience at Bikini has shown that a simple shelter can be very effective in decreasing the extent of radioactive contamination.

CHAPTER XII[1]

PROTECTION OF PERSONNEL

A. INTRODUCTION

TYPES OF DAMAGE

12.1 In the preceding chapters of this book the destructive effects of an atomic bomb have been described and discussed. These effects include damage due to air blast, ground and water shock, thermal radiation, initial nuclear radiations, and residual nuclear radiations. In addition, extensive fires, due to various secondary causes, will follow the atomic explosion. Fortunately, the situation as regards protection from these hazards, although by no means simple, is not as complex as the existence of so many danger factors would imply. In general, it appears that proper protection against blast, shock and fire damage, could also minimize the danger to personnel from thermal radiation and the initial nuclear radiations.

12.2 As far as burning caused by thermal radiation is concerned, the essential points are protection from direct exposure for human beings and the avoidance of easily combustible materials, especially near windows. The only known defense against the gamma rays and neutrons constituting the initial nuclear radiation is the interposition of a sufficient mass of material between the individual and the atomic bomb, including the rising ball of fire. The use of concrete as a construction material, which is necessary to reduce air-blast and ground-shock damage, will, to a great extent, decrease the initial radiation hazard.

12.3 From the standpoint of physical damage, the problems of construction and protection from atomic bombs are not fundamentally different from those associated with bombs of the conventional type. It should not be forgotten, however, that the former are enormously more powerful, and the damage will cover an extensive area, probably several square miles (Fig. 12.3). These facts are important in connection with planning for control of fire-fighting and rescue operations.

12.4 An attempt to indicate the magnitude of the consequences of the explosion of a nominal atomic bomb is illustrated in Figs. 12.4a,

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[1] Material contributed by E. A. Bemis, S. Glasstone, J. O. Hirschfelder, G. M. Lyon, S. B. Smith, W. E. Strope, D. W. Sweeney, T. N. White.

wind, and steps should be taken to reduce to a minimum the inhalation of dust. This would require shutting down the ventilating system and closing all windows and doors in case of an emergency. At distances beyond 12,000 feet from ground zero, many windows would not be broken in an atomic burst, and occupants could remain in buildings with reasonable safety until directed to leave. Provided there were no leakage from outside, air-conditioning systems could remain in operation with advantage.

Outside Shelters

12.52 Shelters outside of larger structures should, in general, be designed to resist the effects of blast and radiation from an atomic bomb at a reasonable distance, say one-half mile. They should be located well clear of buildings to avoid hazard from debris and fire. A buried or semiburied shelter will usually be the best choice for protection from an air burst, as the earth cover will act as a protection against radiation (Figs. 12.52a and b). In addition, blast effects will be less than on a surface shelter. Such buried shelters would, of course, be useless in the event of a nearby underground detonation of an atomic bomb.

Figure 12.52a. Tunnel shelters in hillside, very close to ground zero in Nagasaki, protected the occupants from blast and from thermal and nuclear radiations.

Figure 12.52b. Simple earth and pole shelter, undamaged by fire or blast at 5,000 feet from ground zero, although surrounding buildings were destroyed. (The debris was cleared from the roadway before the photograph was taken.)

12.53 The general aim in structural design of a shelter is to provide strength to resist blast and with sufficient cover to protect against the initial radiations from an atomic bomb. Reinforced concrete is a good constructional material and can be made strong enough to resist the pressures involved. Alternatively, corrugated sheet iron of the type used in culverts has strength and is capable of a high degree of distortion without failure. Wood is also a suitable structural material, but it is less permanent. In each case an adequate layer of soil or of sandbags would be necessary to make a total thickness equivalent to about 2 feet of concrete.

12.54 Tentatively, shelters may be designed for a static load of 500 pounds per square foot, with usual design stresses to provide an adequate factor of safety. Additional allowance should be made for the dead load due to the earth cover, etc., and adequate drainage should be provided. The survival of persons in shelters near ground zero in Japan shows that doors are not needed if a baffle or turn in the entrance shields from the direct heat rays of the bomb. A ramp entrance is preferable to steps, and two means of exit are essential.

12.55 Although there would be little danger from airborne particles contaminated with radioactivity after a high burst, it might be advisable to construct shelters so that they would provide protection in case of surface or subsurface bursts, in which the spread of radiation through the air might be a hazard. Hence, special consideration should be given to the problem of insuring suitable ventilation for shelters.

12.56 The most effective method for providing adequate ventilation is to use a pressurized installation in which the air is forced through special air filters which will remove radioactively contaminated particles.[9] The practicability of such extreme measures, however, is open to question. Air-conditioning and cooling systems where provided can be left in operation for cooling and otherwise improving inside air conditions. The length of time that any structure under these conditions can be occupied without addition of fresh air will depend upon many factors, including the number of people inside, heat transmission through walls, removal of carbon dioxide, etc.

Home Shelters

12.57 Basements of homes, especially if they extended beyond the main structure of the house, would offer reasonable protection against blast damage, provided they are not too near the center of the explosion. However, care must be taken to provide escapes to be used in case the house catches fire or collapses. A shallow rampart of soil or of sand bags outside the house would probably be advantageous. Semiburied shelters for individual families, of the type used in Europe during World War II, for protection against conventional bombs would also provide worthwhile protection against atomic explosions.

Emergency Shelter

12.58 The discussion of shelters, given above, has been based on the tacit assumption that there is sufficient warning of air attack to permit people to take shelter. In the event of a surprise atomic explosion, immediate action could mean the difference between life and death. The first indication of an unexpected atomic burst would be a sudden increase of the general illumination. It would then be imperative to avoid the instinctive tendency to look at the source of this light, but rather to do everything possible to cover all exposed parts of the body.

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[9] The Chemical Warfare Service No. 6 Filter is satisfactory for handling large volumes of air.

12.59 If a person is in the open when the sudden illumination is apparent, then the best plan is instantaneously to drop to the ground, while curling up so as to shade the bare arms and hands, neck, and face with the clothed body. Although this will not protect against gamma rays, it may help in reducing flash burns (§ 6.53). This is important since disabling burns can be suffered well beyond the lethal range for gamma rays (Fig. 12.13). The curled-up position should be held for at least 10 seconds; the immediate danger is then over, and it is permissible to stand up and look around to see what action appears advisable.

12.60 If in the street, and some sort of protection, such as a doorway, a corner or a tree is within a step or two, then shelter may be taken there with the back to the light, and in a crouched position to provide maximum protection, as described above. No attempt should be made to reach a shelter if it is several steps off; the best plan then is to crouch on the ground, as if completely in the open. After 10 seconds, at least, a standing position may be resumed, but it is strongly advisable to press the body tightly against the side of a building to avoid breaking glass or falling missiles, as far as possible.

12.61 A person who is inside a building or home when a sudden atomic bomb attack occurs should drop to the floor, with the back to the window, or crawl behind or beneath a table, desk, counter, etc.; this will also provide a shield against splintered glass due to the blast wave. The latter may reach the building some time after the danger from radiation has passed, and so windows should be avoided for about a minute, since the shock wave continues for some time after the explosion. The safest places inside a building are the interior partitions, and it is desirable to keep as close to these as possible.

D. PROTECTION FROM RESIDUAL RADIATIONS

Introduction

12.62 As stated earlier, protection of large numbers of people from the effects of the residual nuclear radiations, that might follow the explosion of an atomic bomb, represents an entirely new problem concerning which there has been no previous experience. After the attacks on Japan the fission products were so widely dispersed as not to be an appreciable danger; at least, there is no evidence that such a hazard existed. In special circumstances, however, for example, an underwater burst close to the shore or an underground or surface burst, or in the event of the use of radiological warfare weapons, precautions would have to be taken against the residual radiations. In the present section an outline will be given of the general lines of procedure that might be followed for radiological defense; in view of the lack of experience, these may be regarded as tentative and subject to improvement.

12.63 Since the possibility of combating radioactive contamination is bound up with the extent of the associated physical damage, it is desirable to make a rough classification of the possible combinations that might arise. Three general types may be distinguished:

(*a*) *Heavy Physical Damage and Heavy Contamination.*—Such a condition might be due to a combination of an air-burst atomic bomb followed, or accompanied, by the use of a radiological weapon. In view of the wasteful nature of such action, it may be regarded as not too probable, although it cannot be ignored. An underwater burst in a harbor of a large city, close to the shore, might cause both heavy damage and contamination over a limited area. In this event, radiological safety measures might be delayed by the necessity of clearing away debris, establishing communications, etc.

(*b*) *Heavy Physical Damage and Light Contamination.*—This would arise from an atomic explosion of the type experienced at Hiroshima and Nagasaki. The problem of protection against radioactivity would not be serious in this case. It would be necessary for monitoring teams to follow the radioactive cloud downwind in case there were a marked fall-out in any particular area. It is of almost equal importance to know definitely that there is no hazard.

(*c*) *Moderate or Little Physical Damage and Moderate to Heavy Contamination.*—Such circumstances could arise from a radiological warfare attack, from dry or wet fall-out, from base surge on a ship or on shore at some distance from an underwater explosion, or from an ineffective ("fizzle") explosion of an atomic bomb. The radioactive protection would be of the greatest significance, and to meet these conditions the radiological defense system must be especially prepared.

STAGES OF DISASTER

12.64 In considering the practical problems of a radiological hazard it may be supposed that there will be three stages, the duration and severity of which will depend on circumstances described above. These are as follows:

(*a*) *Complete Disorganization.*—In the event of heavy and widespread physical damage, it may be presumed that roads will be blocked for some distance from the explosion, and that all normal communication systems will be out of commission. Emergency transportation and communication, except perhaps for self-contained radio equipment, will not be immediately in effect.

(*b*) *Emergency Control Stage.*—This phase will begin as soon as margin roads have been cleared, and transportation and communication has been reestablished, at least on an emergency scale, so that information can be transmitted to a control room. In the case of moderate physical disaster (§ 12.63 (*c*)), the emergency control phase would start immediately, and might last a week or more.

(*c*) *Recovery Stage.*—The final phase would be reached when most people were out of immediate danger of injury, and there is time to start more thorough decontamination operations where necessary (Chapter X).

12.65 In the emergency control phase, an important factor in the operation of radiological defense is the rapid gathering of data regarding contamination. The radiations which may be encountered are gamma rays and beta particles from fission products, neutron-induced activity or other radioactive material, and alpha particles from plutonium or uranium. Of these, the gamma radiation can be measured most readily; this is perhaps the greatest immediate hazard because of its considerable penetrating power. Beta particles as such are not a serious menace unless the source enters the system or remains on the skin for some time.

12.66 Monitoring of suspected contaminated areas for gamma radiation should be carried out at the earliest possible moment after an atomic explosion in which such contamination is likely to have been produced. Initially, this might even be done by means of low-flying aircraft; from the gamma radiation dosage measured at a known height above the ground it will be possible to obtain an approximate indication of the area and intensity of contamination (see Fig. 8.35). However, ground monitoring for gamma radiation, with portable instruments, will be necessary at the first opportunity. The monitoring for beta radiation will, in general, be an auxiliary measurement, made in the later stages after the immediate emergency has passed.

12.72 In the recovery stage, the main objective would be to achieve as effective decontamination as possible so as to reduce the general contamination level to that permitted for routine workers with radioactive material, e. g., 0.3 r per week (§ 8.4). Although there is not complete agreement on the subject, because of the lack of adequate knowledge, the information given in Table 12.72 may be taken as indicating a few approximate permissible contamination levels for continued exposure. It is assumed that plutonium is the alpha emitter, since this is probably the most dangerous of those likely to be encountered.

TABLE 12.72

PERMISSIBLE CONTAMINATION

Contaminated material	*Fission product*	*Alpha-emitter*
Air	2×10^{-10} microcurie/cc	2.5×10^{-11} microgram/cc.
Water	4×10^{-6} microcurie/cc	2×10^{-5} microgram/cc.

12.73 It should be noted that the figures given in the table refer to permissible levels for personnel exposed to radiation every day, as a result of their peacetime occupation.

12.74 With regard to the internal radiation hazard, it is not possible to make any sound estimate of the amount of material which is likely to be ingested in various circumstances. A person working under normal indoor conditions, for example, would absorb much less than one engaged in an occupation in which there was much dust. Children, because of their habits and closeness to the ground, would be expected to ingest more than adults. These factors would greatly complicate a rehabilitation program, and make it almost impossible to attempt to assess universal permissible contamination levels.

MONITORING EQUIPMENT

12.75 All emergency workers, no matter what their duties, who are sent into areas contaminated with beta or gamma radiation, should be provided with, or closely accompanied by, instruments for personnel monitoring (see Chapter IX). During the disorganization phase and for part, at least, of the emergency control phase, these would have to be of the self-reading, pocket dosimeter type. Instruments of various total ranges, in roentgens, are available, and it would be necessary to use the particular range appropriate to the work to be undertaken. Provision must be made for recharging the dosimeters after each period of use, for otherwise they would be valueless.

The Effects of
Nuclear Weapons

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2.51 In the course of its rapid expansion, the hot gas bubble, while still under water, initiates a shock wave. The trace of this wave, as it moves outward from the burst, is evident, on a reasonably calm surface, as a rapidly advancing circle, apparently whiter than the surrounding water. This phenomenon, sometimes called the "slick," is visible in contrast to the undisturbed water because small droplets of water at the surface are hurled short distances into the air, and the resulting entrainment of air makes the shocked water surface look white.

2.52 Following immediately upon the appearance of the slick, and prior to the formation of the Wilson cloud, a mound or column of broken water and spray, called the "spray dome," is thrown up over the point of the burst (Fig. 2.52). This is a consequence of the reflection of the shock wave at the surface. The initial upward velocity of the water is proportional to the pressure of the direct shock wave, and so it is greatest directly above the detonation point. Consequently, the water in the center rises more rapidly (and for a longer time) than water farther away. As a result, the sides of the spray dome become steeper as the water rises. The upward motion is terminated by the downward pull of gravity and the resistance of the air. The total time of rise and the maximum height attained depend upon the energy of the explosion, and upon its depth below the water surface. For a very deep underwater burst, the spray dome may not be visible at all.

2.53 If the depth of burst is not too great, the bubble of hot, compressed gases remains essentially intact until it rises to the surface of the water. At this point the gases, carrying some liquid water by entrainment, are expelled into the atmosphere. Part of the shock wave passes through the surface into the air and because of the high humidity, the conditions are suitable for the formation of a condensation cloud (Fig. 2.53a). As the pressure of the bubble is released, water rushes into the cavity, and the resultant complex phenomena cause the water to be thrown up as a hollow cylinder or chimney of spray called the "column." The radioactive contents of the gas bubble are vented through this hollow column and form a cauliflower-shaped cloud at the top (Fig. 2.53b).

2.54 In the shallow underwater (BAKER) burst at Bikini, the spray dome began to form at about 4 milliseconds after the explosion. Its initial rate of rise was roughly 2,500 feet per second, but this was rapidly diminished by air resistance and gravity. A few milliseconds later, the hot gas bubble reached the surface of the lagoon and the column began to form, quickly overtaking the spray dome. The maxi-

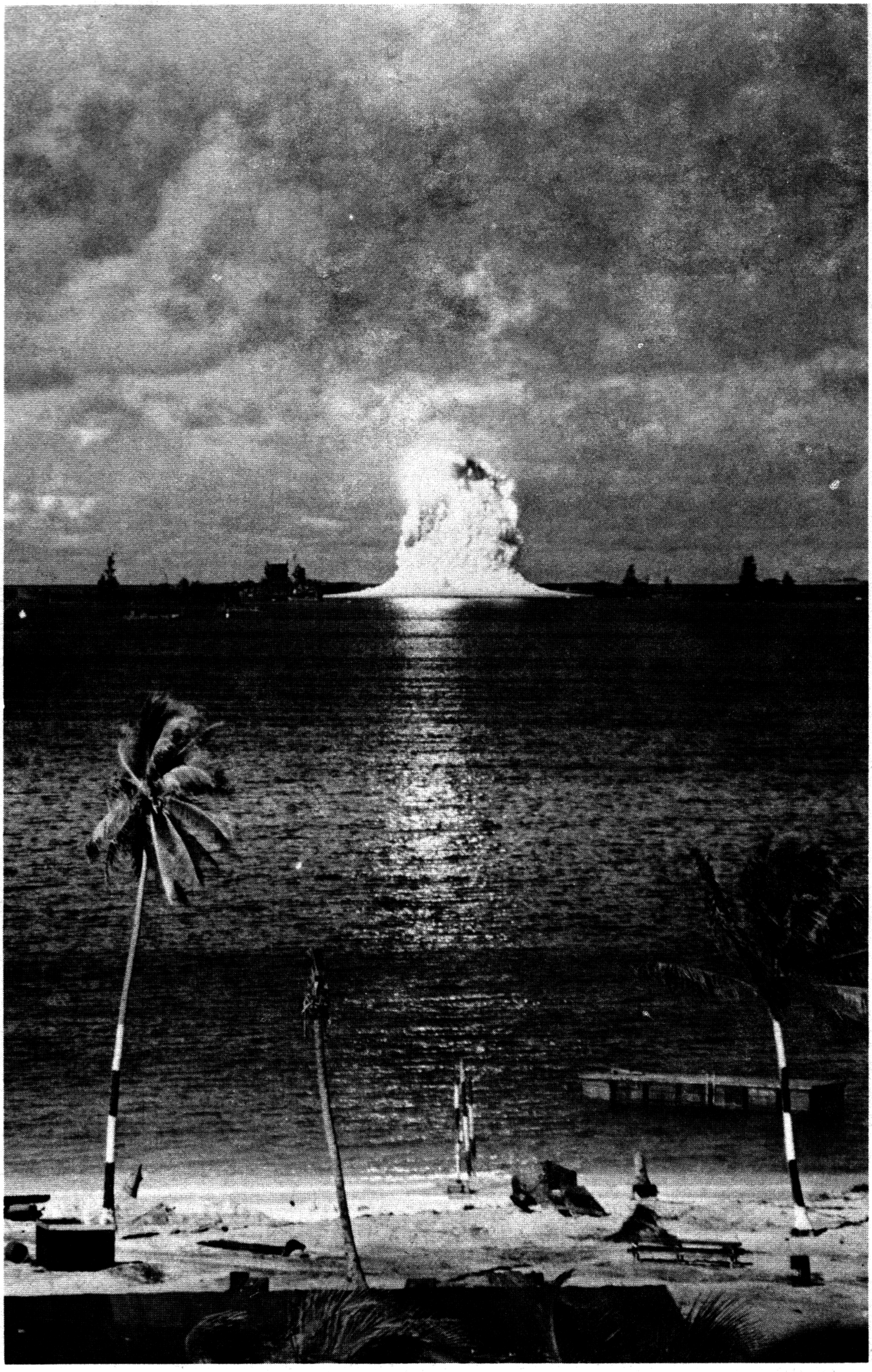

Figure 2.52. The "spray dome" formed over the point of burst in an underwater explosion.

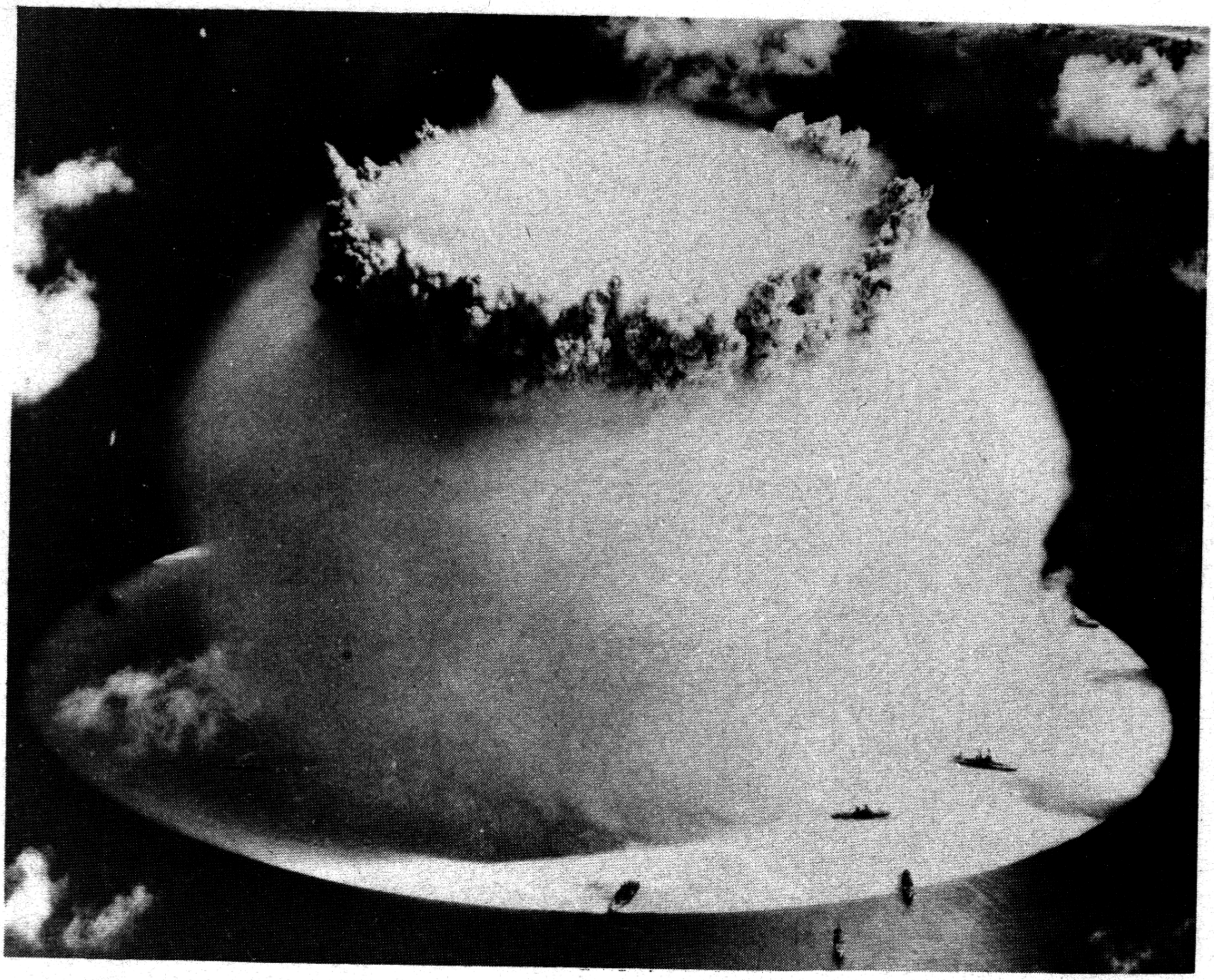

Figure 2.53a. The condensation cloud formed after a shallow underwater explosion. (The "slick," due to the shock wave, can be seen on the water surface.)

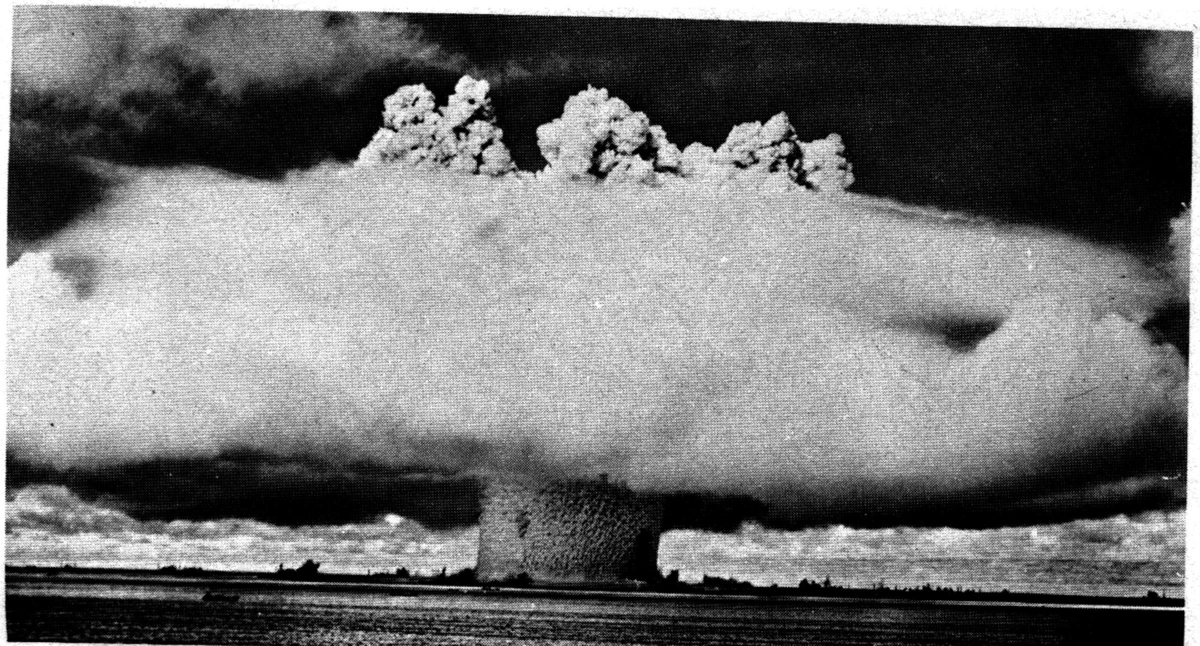

Figure 2.53b. Formation of the hollow column in an underwater explosion, the top is surrounded by a late stage of the condensation cloud.

mum height attained by the hollow column, through which the gases vented, could not be estimated exactly because the upper part was surrounded by the atomic cloud (Fig. 2.54). The column was probably some 6,000 feet high and the maximum diameter was about 2,000 feet. The walls were probably 300 feet thick, and approximately a million tons of water were raised in the column.

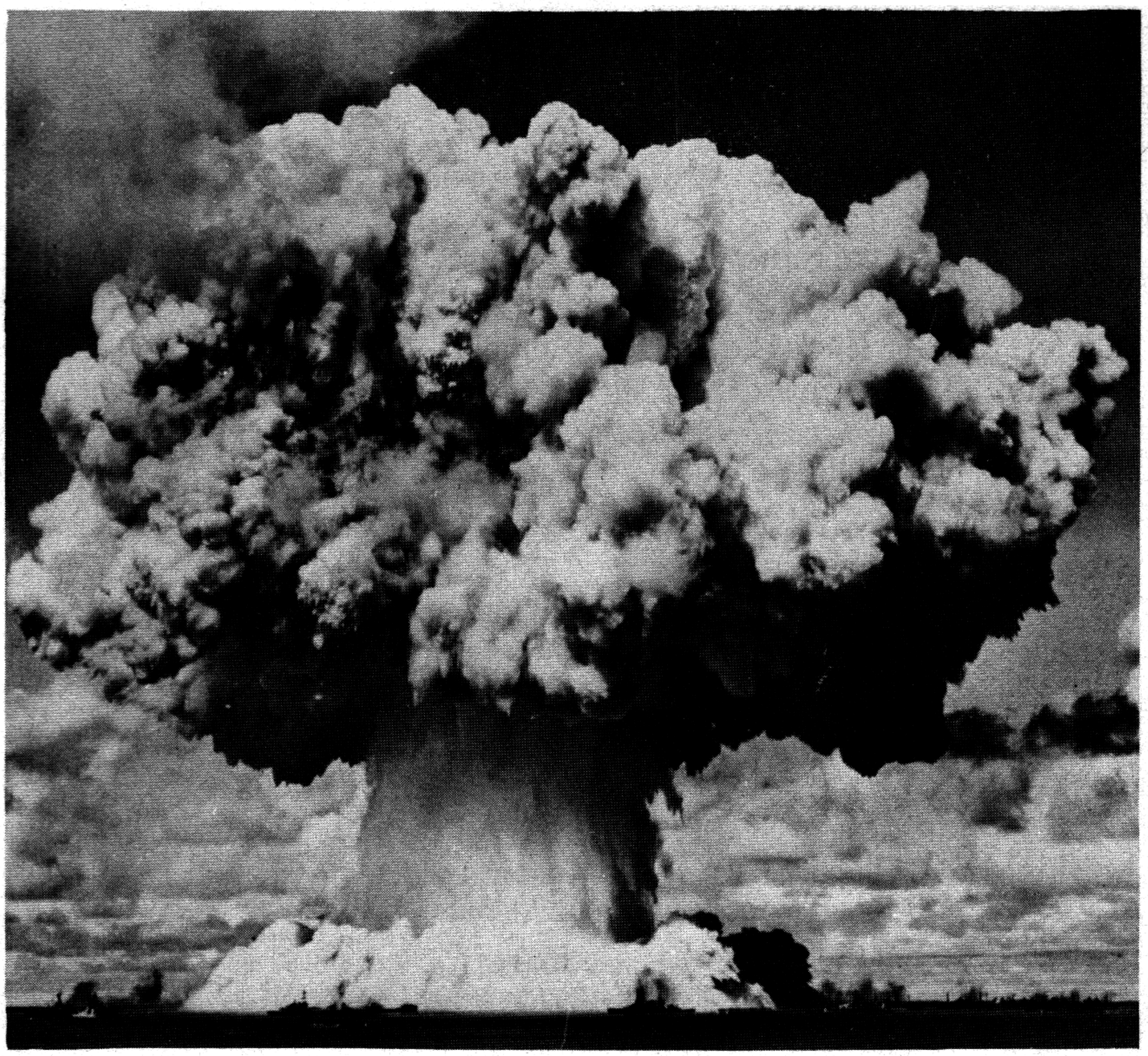

Figure 2.54. **The radioactive cloud and first stages of the base surge following an underwater burst. Water is beginning to fall back from the column into the lagoon.**

2.55 The cauliflower-shaped cloud, which concealed part of the upper portion of the column, contained some of the fission products and other bomb residues, as well as a large quantity of water in small droplet form. In addition, there is evidence that material sucked up from the bottom of the lagoon was also present, for a calcareous (or chalky) sediment, which must have dropped from the atomic cloud, was found on the decks of ships some distance from the burst. The cloud was roughly 6,000 feet across and ultimately rose to a height of nearly 10,000 feet before being dispersed. This is considerably less than the height attained by an atomic cloud in an air burst.

2.56 The disturbance created by the underwater burst caused a series of waves to move outward from the center of the explosion across the surface of Bikini lagoon. At 11 seconds after the detonation, the first wave had a maximum height of 94 feet and was about 1,000 feet from surface zero. This moved outward at high speed and was followed by a series of other waves. At 22,000 feet from surface zero, the ninth wave in the series was the highest with a height of 6 feet.

The Base Surge

2.57 As the column of water and spray fell back into the lagoon in the BAKER test, there developed a gigantic wave (or cloud) of mist completely surrounding the column at its base (Fig. 2.54). This doughnut-shaped cloud, moving rapidly outward from the column, is called the "base surge." It is essentially a dense cloud of water droplets, much like the spray at the base of Niagara Falls (or other high waterfalls), but having the property of flowing almost as if it were a homogeneous fluid.

2.58 The base surge at Bikini commenced to form at 10 or 12 seconds after the detonation. The surge cloud, billowing upward, rapidly attained a height of 900 feet, and moved outward at an initial rate of more than a mile a minute. Within 4 minutes the outer radius of the cloud, growing rapidly at first and then more slowly, was nearly 3½ miles across and its height had then increased to 1,800 feet. At this stage, the base surge gradually rose from the surface of the water and began to merge with the atomic cloud and other clouds in the sky (Fig. 2.58).

2.59 After about 5 minutes, the base surge had the appearance of a mass of strato-cumulus clouds which eventually reached a thickness of several thousand feet (Fig. 2.59). A moderate to heavy rainfall, moving with the wind and lasting for nearly an hour, developed from the cloud mass. In its early stages the rain was augmented by the small water droplets still descending from the atomic cloud.

2.60 From the weapons effects standpoint, the importance of the base surge lies in the fact that it is likely to be highly radioactive due to fission products present either at its inception, or dropped into it from the atomic cloud. Because of its radioactivity, it may represent a serious hazard for a distance of several miles, especially in the downwind direction (see Chapter IX). Any object over which

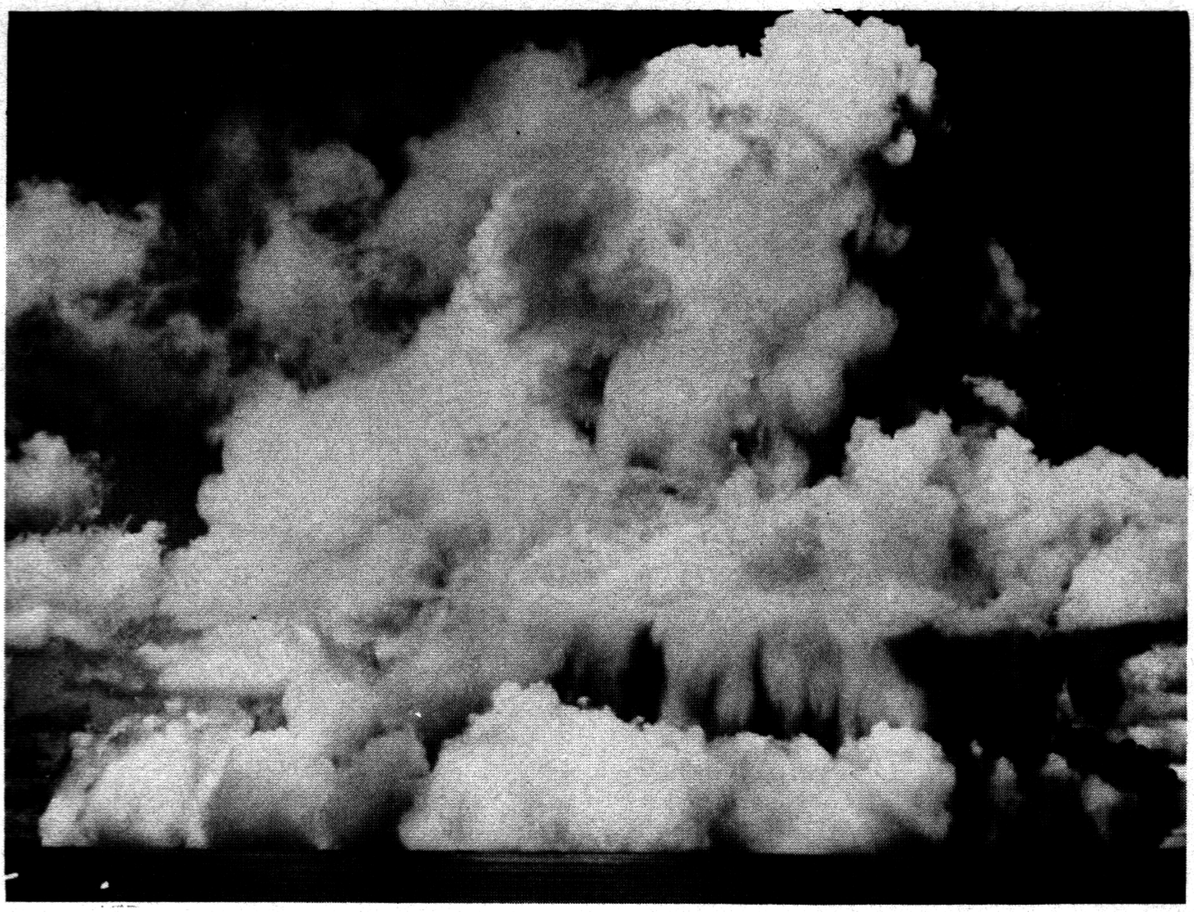

Figure 2.58. **The development of the base surge following an underwater explosion.**

the base surge passes is likely to become contaminated, due to the deposition of water droplets to which fission products may have become attached. The base surge and the fallout or "rainout" from the atomic cloud constitute the sources of the residual nuclear radiation following an underwater nuclear explosion.

2.61 The necessary conditions for the formation of a base surge have not been definitely established. However, base surge formation will occur if an appreciable column is formed. The probability of such an occurrence increases with an increase in the depth of burst, up to reasonable depths.

2.62 In the event of a sufficiently deep underwater nuclear explosion, the hot gas bubble loses its identity in a mass of turbulent water before reaching the surface. In these circumstances, there is no large column of water and spray and, hence, little or no base surge. The disintegration of the gas bubble into a large number of small bubbles, which are churned up with the water, will produce a radioactive foam or froth. When this reaches the surface, a small amount of mist is formed, but most of the activity is retained in the water. There is thus

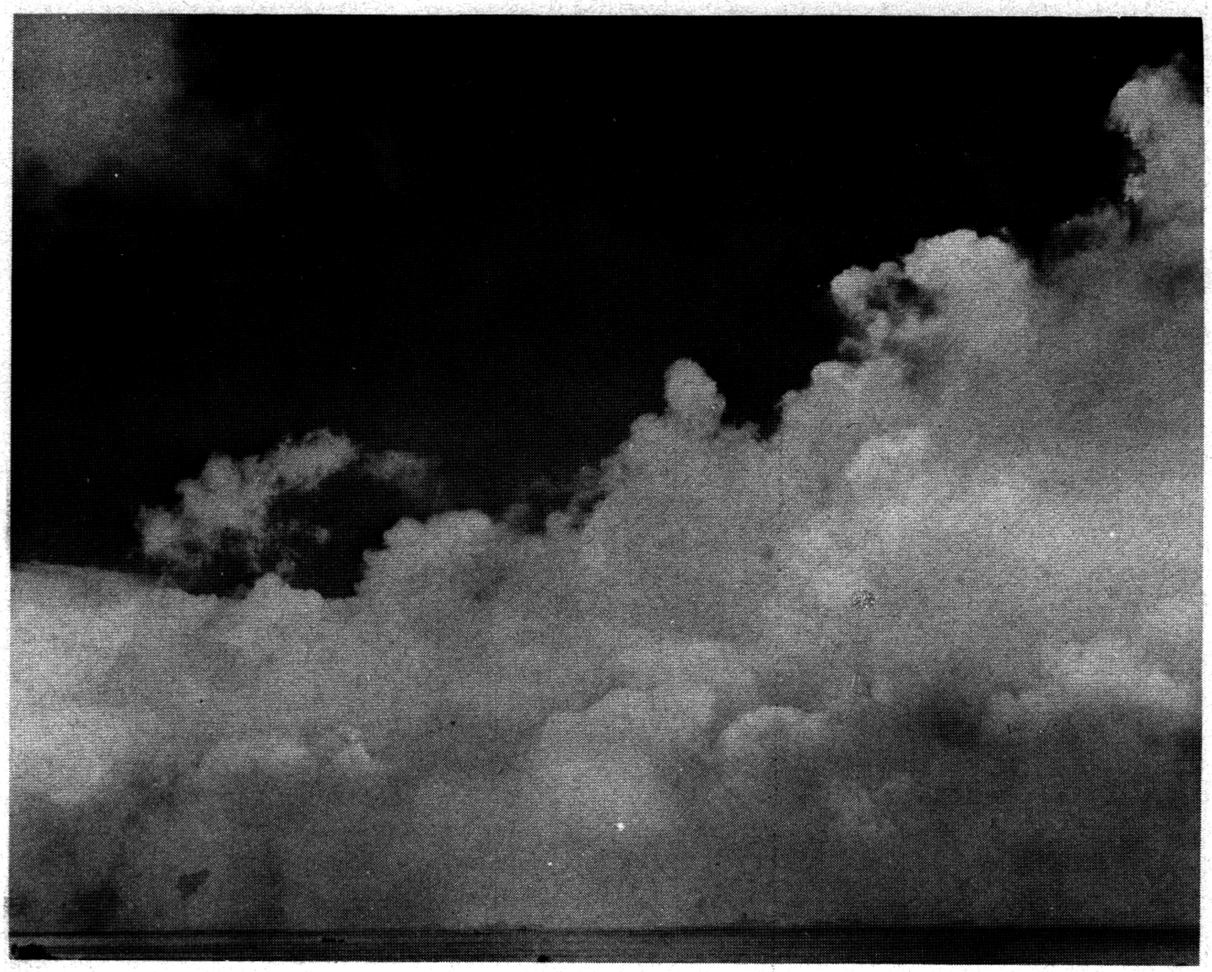

Figure 2.59. Final stage in the development of the base surge.

no atomic cloud from a deep underwater burst and, consequently, no extensive fallout. The deposition of the highly active foam on a nearby shore, however, could constitute a hazard.

THERMAL AND NUCLEAR RADIATIONS

2.63 Essentially all the thermal radiation emitted by the ball of fire while it is still submerged is absorbed by the surrounding water. When the hot gases reach the surface and expand, the cooling is so rapid that the temperature drops almost immediately to a point where there is no further appreciable emission of thermal radiation. It follows, therefore, that in an underwater nuclear explosion the thermal radiation can be ignored, as far as its effects on personnel and as a source of fire are concerned.

2.64 It is probable, too, that most of the neutrons and gamma rays liberated within a short time of the initiation of the explosion will also be absorbed by the water. But, when the fireball reaches the surface and the gases are expelled, the gamma rays (and beta particles) from the fission products will represent a form of initial nuclear radiation. In addition, the radiation from the fission (and induced radioactive) products, present in the column, atomic cloud, and base surge, all three of which are formed within a few seconds of the burst, will contribute to the initial effects.

2.65 However, the water fallout (or rainout) from the cloud and the base surge are also responsible for the residual nuclear radiations, as described above. For an underwater burst, it is thus less meaningful to make a sharp distinction between initial and residual radiations, such as is done in the case of an air burst. The initial nuclear radiations merge continuously into those which are produced over a period of time following the nuclear explosion.

CHRONOLOGICAL DEVELOPMENT OF A SHALLOW UNDERWATER BURST

2.66 The series of drawings in Figs. 2.66a to 2.66e give a schematic representation of the chronological development of the phenomena associated with a shallow, underwater burst of a 100-kiloton nuclear bomb. The data supplement the information relating to a 20-kiloton explosion given above. Essentially all the effects, other than the shock front and the nuclear radiation, are visible to the eye.

DESCRIPTION OF AN UNDERGROUND BURST

UNDERGROUND EXPLOSION PHENOMENA

2.67 When a nuclear bomb is exploded under the ground, a ball of fire is formed consisting of extremely hot gases at high pressures, including vaporized earth and bomb residues. If the detonation occurs at not too great a depth, the fireball may be seen as it breaks through the surface, before it is obscured by clouds of dirt and dust. As the gases are released, they carry up with them into the air large quantities of earth, rock, and debris in the form of a cylindrical column, analogous to that observed in an underwater burst. In the underground test explosion at a shallow depth, made in Nevada in 1951, the column assumed the shape of an inverted cone, fanning out as it rose to cause a radial throw-out (Fig. 2.67). Because of the large amount of material removed by the explosion, a crater of considerable size was left in the ground.

2.68 It is estimated from tests made in Nevada that, if a 1-megaton bomb were dropped from the air and penetrated underground in

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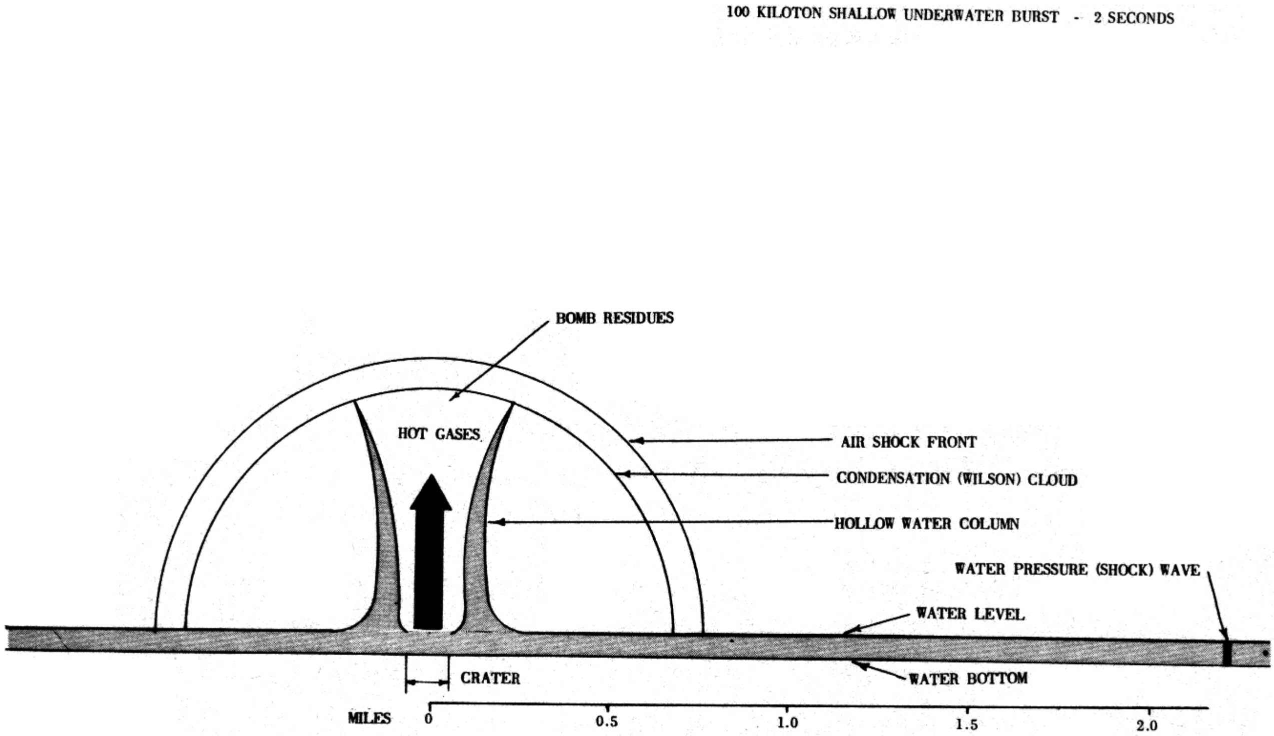

Figure 2.66a. **Chronological development of a 100-kiloton shallow underwater burst: 2 seconds after detonation.**

When a nuclear bomb is exploded under the surface of water, a bubble of intensely hot gases is formed which will burst through the surface if the detonation occurs at a shallow depth. As a result, a hollow column of water and spray is shot upward, reaching a height of over 5,000 feet in 2 seconds after a 100-kiloton explosion. The gaseous bomb residues are then vented through the hollow central portion of the water column.

The shock (or pressure) wave produced in the water by the explosion travels outward at high speed, so that at the end of 2 seconds it is more than 2 miles from surface zero. The expansion of the hot gas bubble also results in the formation of a shock (or blast) wave in the air, but this moves less rapidly than the shock wave in water, so that the front is some 0.8 mile from surface zero.

Soon after the air shock wave has passed, a dome-shaped cloud of condensed water droplets, called the condensation cloud, is formed for a second or two. Although this phenomenon is of scientific interest, it has apparently no significance as far as nuclear attack or defense is concerned.

For an underwater burst at moderate (or great) depth, essentially all of the thermal radiation and much of the initial nuclear radiation is absorbed by the water.

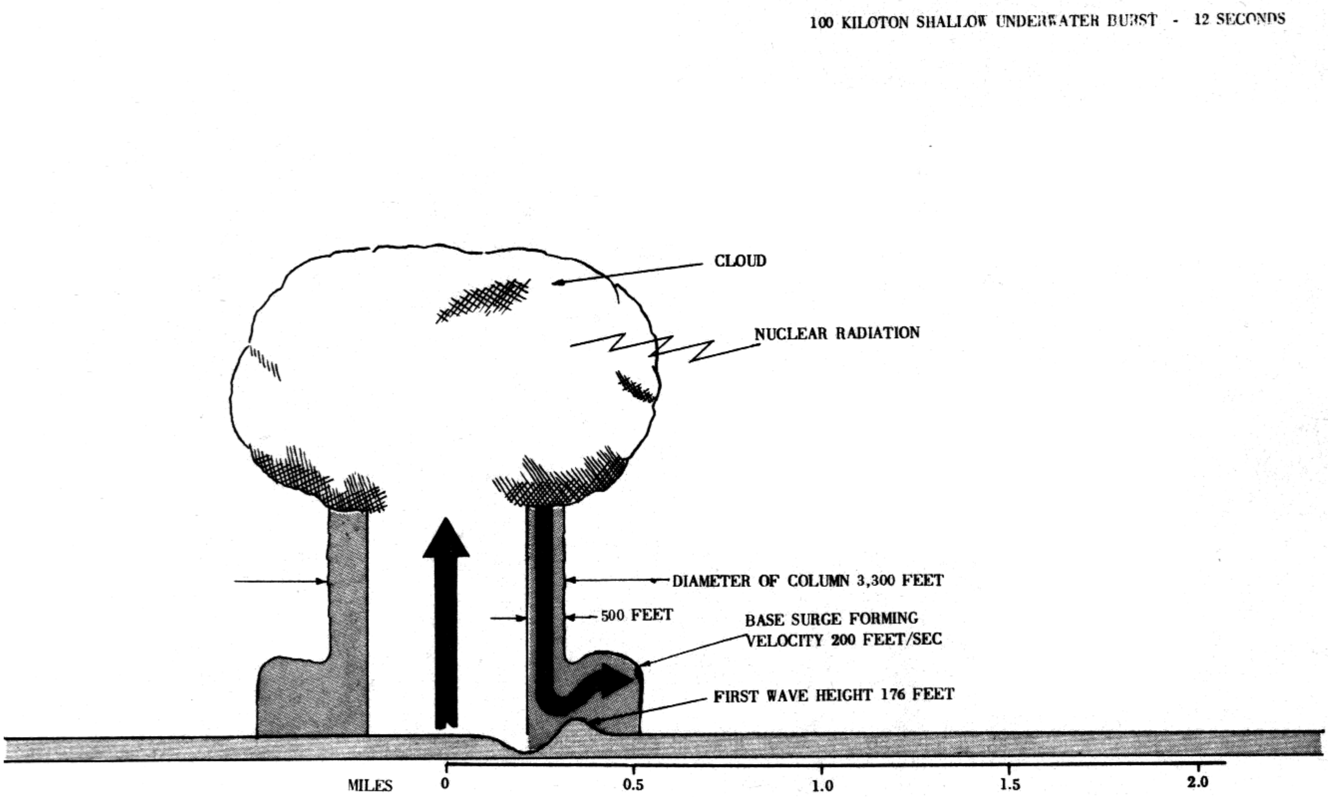

Figure 2.66b. Chronological development of a 100-kiloton shallow underwater burst: 12 seconds after detonation.

At 12 seconds after the 100-kiloton explosion, the diameter of the water column is about 3,300 feet, and its walls are some 500 feet thick. The bomb residues venting through the hollow central portion condense and spread out to form the cauliflower-shaped atomic cloud, partly obscuring the top of the column. The cloud is highly radioactive, due to the presence of fission products, and hence it emits nuclear radiations. Because of the height of the cloud these radiations are a minor hazard to persons near the surface of the water.

At 10 to 12 seconds after a shallow underwater explosion, the water falling back from the column reaches the surface and produces around the base of the column a ring of highly radioactive mist, called the base surge. This ring-shaped cloud moves outward, parallel to the water surface, at high speed, initially 200 feet per second (135 miles per hour).

The disturbance due to the underwater explosion causes large water waves to form on the surface. At 12 seconds after a 100-kiloton explosion, the first of these is about 1,800 feet (0.34 mile) from surface zero, and its height, from crest to trough, is 176 feet.

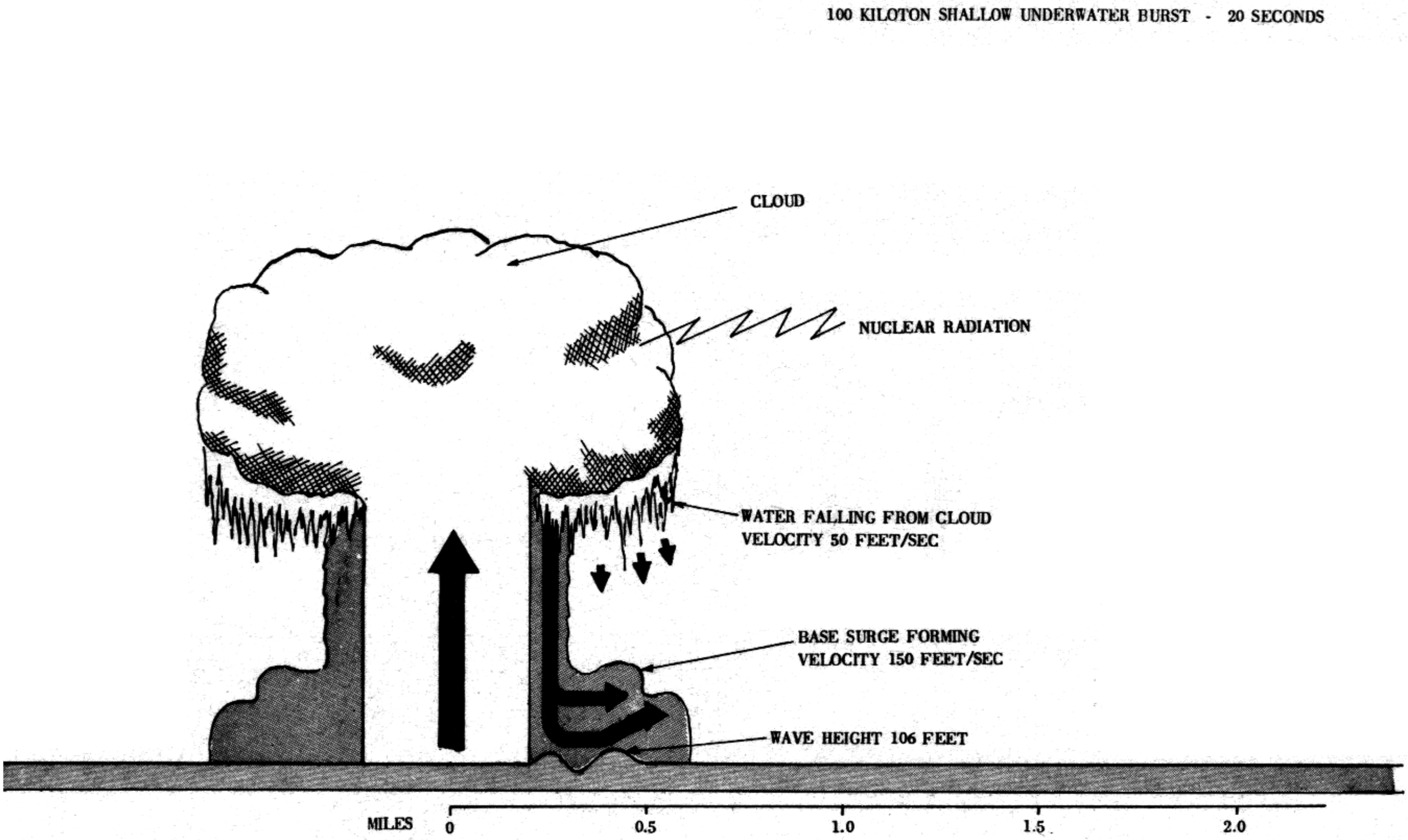

Figure 2.66c. Chronological development of a 100-kiloton shallow underwater burst: 20 seconds after detonation.

As the water and spray forming the column continue to descend, the base surge cloud develops, billowing upward and moving outward across the surface of the water. At 20 seconds after the 100-kiloton explosion the height of the base surge is about 1,000 feet and its front is nearly ½ mile from surface zero. It is then progressing outward at a rate of approximately 150 feet per second (100 miles per hour).

At about this time, large quantities of water, sometimes referred to as the massive water fallout, begin to descend from the atomic cloud. The initial rate of fall is about 50 feet per second. Because of the loss of water from the column, in one way or another, its diameter has now decreased to 2,000 feet.

By the end of 20 seconds, the first water wave has reached about 2,000 feet (0.38 mile) from surface zero and its height is roughly 106 feet.

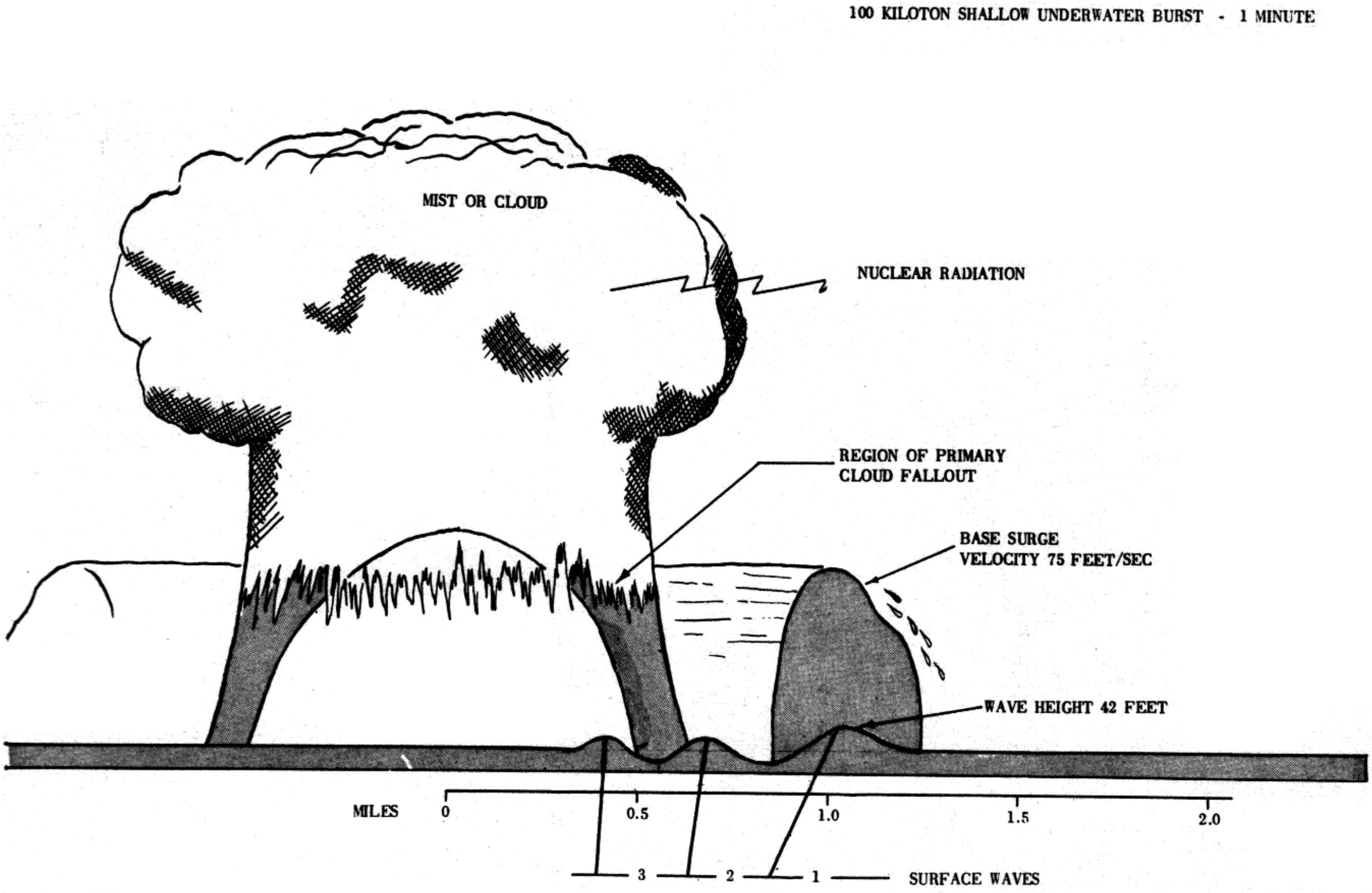

Figure 2.66d. Chronological development of a 100-kiloton shallow underwater burst: 1 minute after detonation.

At 1 minute after the underwater burst, the water falling from the atomic cloud reaches the surface, forming a region of primary cloud fallout. There is consequently a continuous ring of water and spray between the cloud and the surface of the water.

At about this time, the base surge has become detached from the bottom of the column, so that its ring-like character is apparent. The height of the base surge cloud is now 1,300 feet and its front, moving outward at some 75 feet per second (50 miles per hour), is about 1.2 miles from surface zero. Because of the radioactivity of the water droplets constituting the base surge, the latter represents a hazard to personnel.

Several water waves have now developed, the first, with a height of 42 feet, being approximately 1 mile from surface zero.

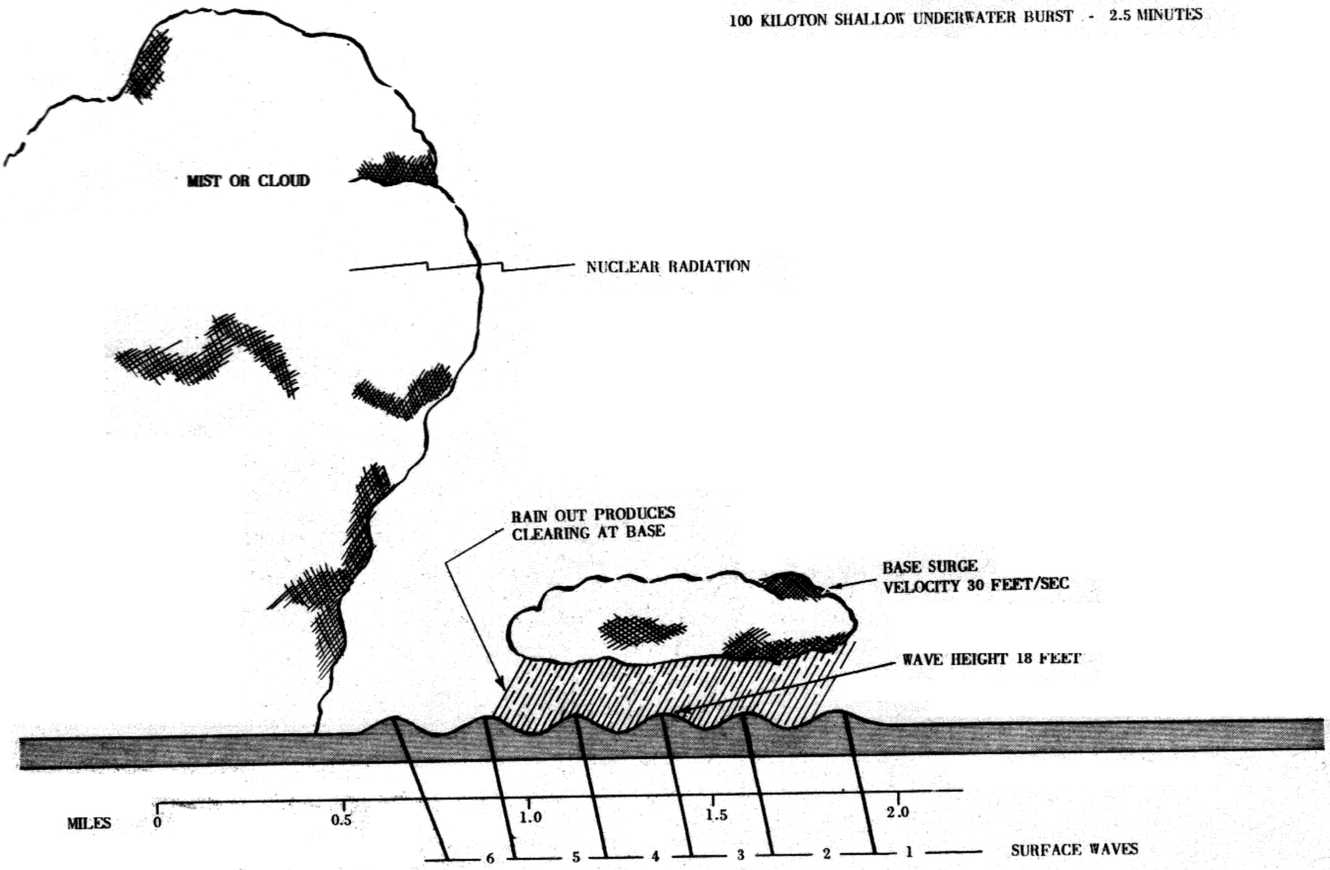

Figure 2.66e. Chronological development of a 100-kiloton shallow underwater burst: 2.5 minutes after detonation.

By 2½ minutes after the 100-kiloton underwater explosion, the front of the base surge is nearly 2 miles from ground zero and its height is roughly 2,000 feet. The greatest effective spread of the base surge cloud, reached in 4 minutes, is approximately 2½ miles from surface zero, i. e., 5 miles across. The base surge now appears to be rising from the surface of the water. This effect is attributed to several factors, including an actual increase in altitude, thinning of the cloud by engulfing air, and raining out of the larger drops of water. Owing to natural radioactive decay of the fission products, to rainout, and to dilution of the mist by air, the intensity of the nuclear radiation from the base surge at 2½ minutes after the explosion is only one-twentieth of that at 1 minute.

The descent of water and spray from the column and from condensation in the atomic cloud results in the formation of a continuous mass of mist or cloud down to the surface of the water. Ultimately, this merges with the base surge, which has spread and increased in height, and also with the natural clouds of the sky, to be finally dispersed by the wind.

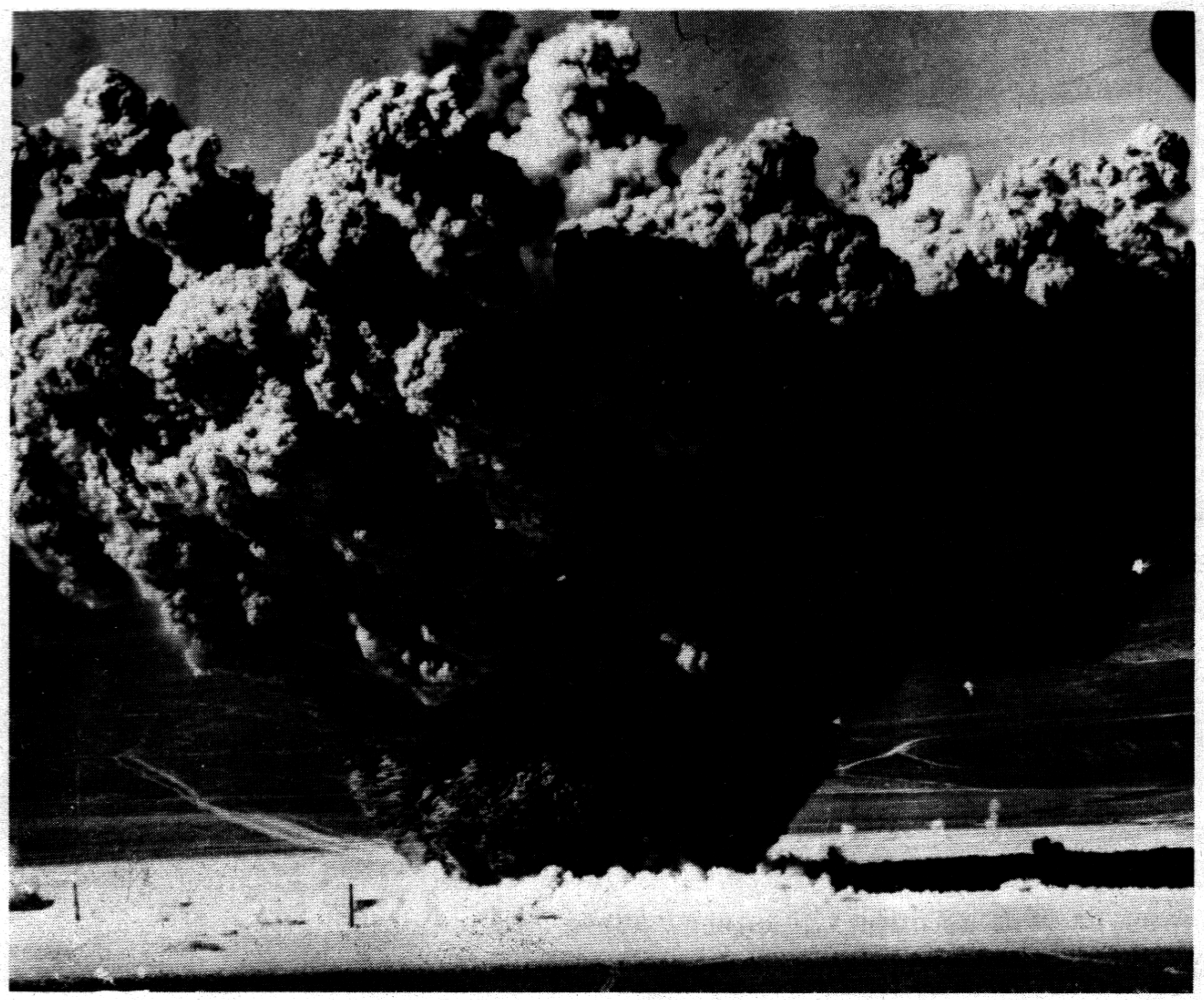

Figure 2.67. Shallow underground burst.

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sandy soil to a depth of 50 feet before exploding, the resulting crater would be about 190 feet deep and nearly 1,400 feet across. This means that approximately 10 million tons of soil and rock would be hurled upward from the earth's surface. The volume of the crater and the mass of material thrown up by the force of the explosion will increase roughly in proportion to the energy of the bomb. As they descend to earth, the finer particles of soil may initiate a base surge, as will be described below.

2.69 The rapid expansion of the bubble of hot, high-pressure gases formed in the underground burst initiates a shock wave in the earth. Its effects are somewhat similar to those of an earthquake of moderate intensity, except that the disturbance originates fairly near the surface instead of at a great depth. The difference in depth of origin means that the pressures in the underground shock wave caused by a nuclear bomb probably fall off more rapidly with distance than do those due to earthquake waves. Further, both the energy of a nuclear explosion and the duration of the shock wave are less than for an earthquake.

2.70 As in an underwater burst, part of the energy released by the bomb in an underground explosion appears as a blast wave in the air. The fraction of the energy imparted to the air in the form of blast depends primarily upon the depth of the burst. The greater the penetration of the bomb before detonation occurs, the smaller is the proportion of the shock energy that escapes into the air.

Base Surge and Fallout

2.71 When the material thrown up as a column of dirt in an underground explosion falls back to earth, it will, in many instances, produce an expanding cloud of fine soil particles similar to the base surge observed in the Bikini BAKER test. For example, the early stages of a base surge formation can be seen in Fig. 2.71, which resembles Fig. 2.58 in many respects. The base surge of dirt particles moves outward from the center of the explosion and is subsequently carried downwind. Eventually the particles settle out and produce radioactive contamination over a large area, the extent of which will depend upon the depth of burst, the nature of the soil, and the atmospheric conditions, as well as upon the energy yield of the bomb. It is believed that a dry sandy terrain will be particularly conducive to base surge formation in an underground burst.

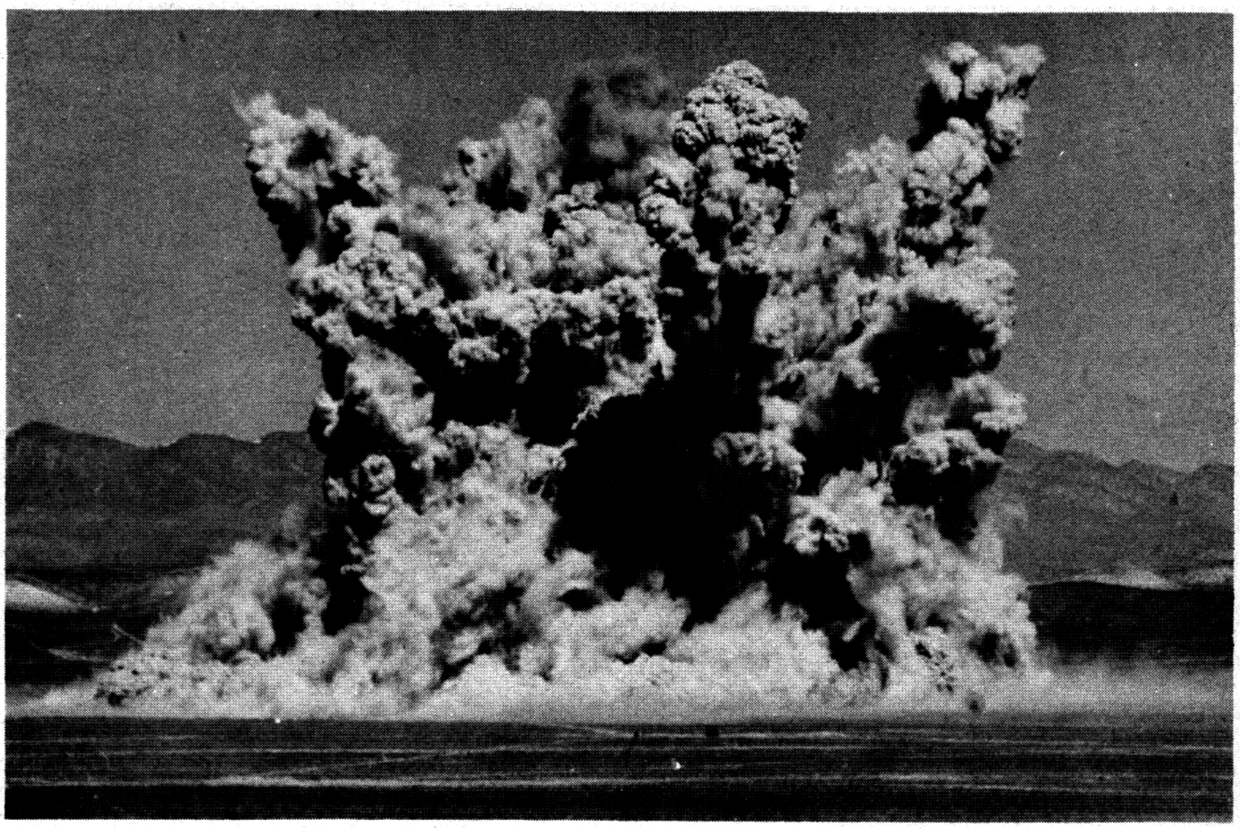

Figure 2.71. Base surge formation in underground burst.

2.72 The atomic cloud resulting from an underground explosion will inevitably contain a very large amount of soil, rocks, and a variety of debris. There will, consequently, be a considerable fallout of contaminated matter. The larger pieces thrown up by the explosion will be the first to reach the earth and so they will be deposited near the location of the burst. But the smaller particles will remain suspended in the air for some time and may be carried great distances by the wind before they eventually settle out.

THERMAL AND NUCLEAR RADIATIONS

2.73 The situation as regards thermal and nuclear radiations from an underground burst are quite similar to those described above in connection with an underwater explosion. As a general rule, the thermal radiation will be almost completely absorbed by the soil material, so that it does not represent a significant hazard. Most of the neutrons and early gamma rays will also be removed, although the capture of the neutrons may cause a considerable amount of induced radioactivity in various materials present in the soil. This will constitute a small part of the residual nuclear radiation, of importance only in the close vicinity of the point of burst. The remainder of the residual radiation will be due to the contaminated base surge and fallout.

2.74 For the same reasons as were given in § 2.64 for an underwater burst, the initial and residual radiations from an underground burst tend to merge into one another. The distinction which is made in the case of an air burst is consequently less significant in a subsurface explosion.

CHRONOLOGICAL DEVELOPMENT OF A SHALLOW UNDERGROUND BURST

2.75 The chronological development of some of the phenomena associated with an underground nuclear explosion, having an energy yield of 100 kilotons, at a shallow depth is represented by Figs. 2.75a to 2.75d.

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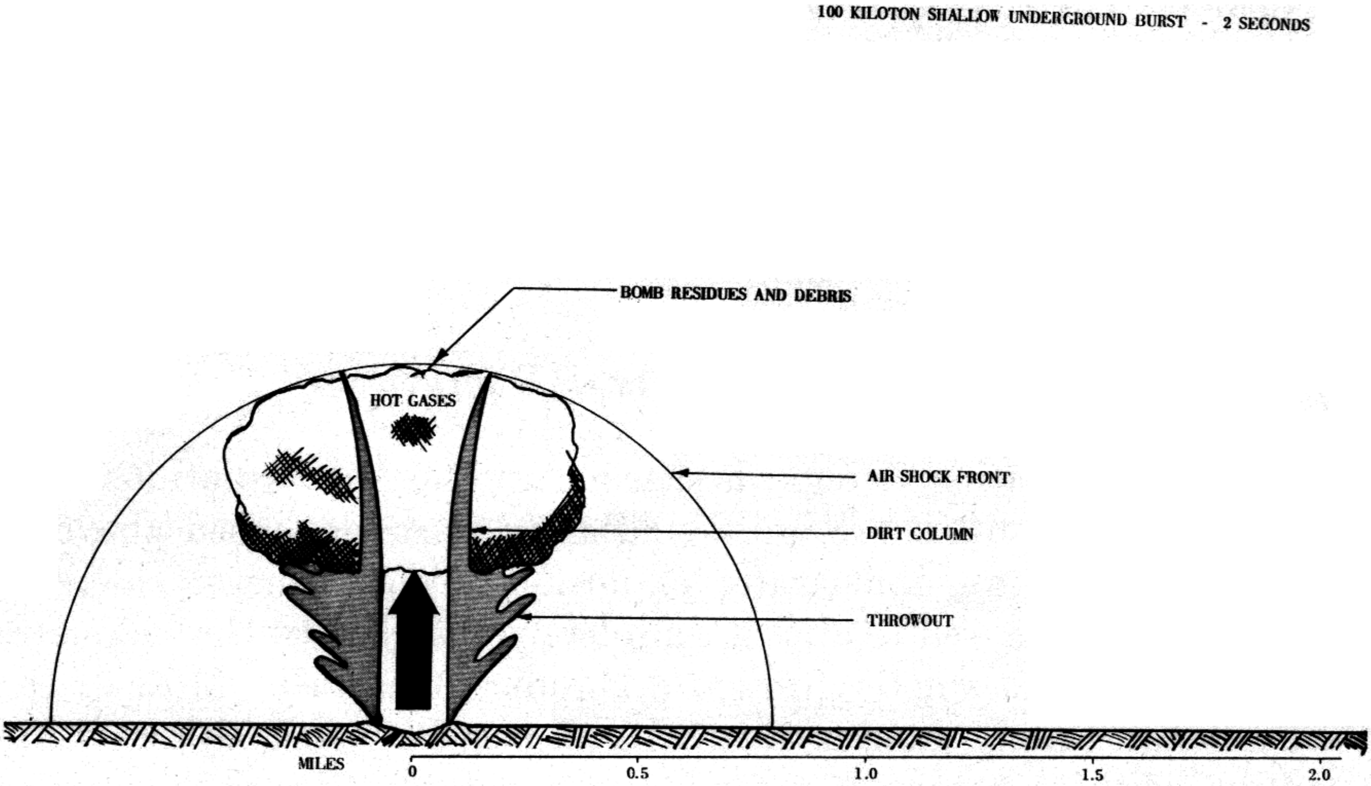

Figure 2.75a. Chronological development of a 100-kiloton shallow underground burst: 2.0 seconds after detonation.

When a nuclear explosion occurs at a shallow depth underground, the ball of fire breaks through the surface of the earth within a fraction of a second of the instant of detonation. As the fireball penetrates the surface, the intensely hot gases at high pressure are released and they carry up with them into the air large quantities of soil, rock, and debris in the form of a hollow column. For a burst at a shallow depth, the column tends to assume the shape of an inverted cone which fans out as it rises to produce a radial throw-out. A highly radioactive cloud, which contains large quantities of earth, is formed above the throw-out as the hot vapors cool and condense. Because of the mass displacement of material from the earth's surface, a crater is formed. For a 100-kiloton bomb exploding 50 feet beneath the surface of dry soil, the crater would be about 120 feet deep and 720 feet across. The weight of the material removed would be over a million tons.

In addition to the shock (or pressure) wave in the ground, somewhat related to an earthquake wave, the explosion is accompanied by a shock (or blast) wave in the air. At 2 seconds after the explosion, the shock front in air is about ¾ mile from surface zero.

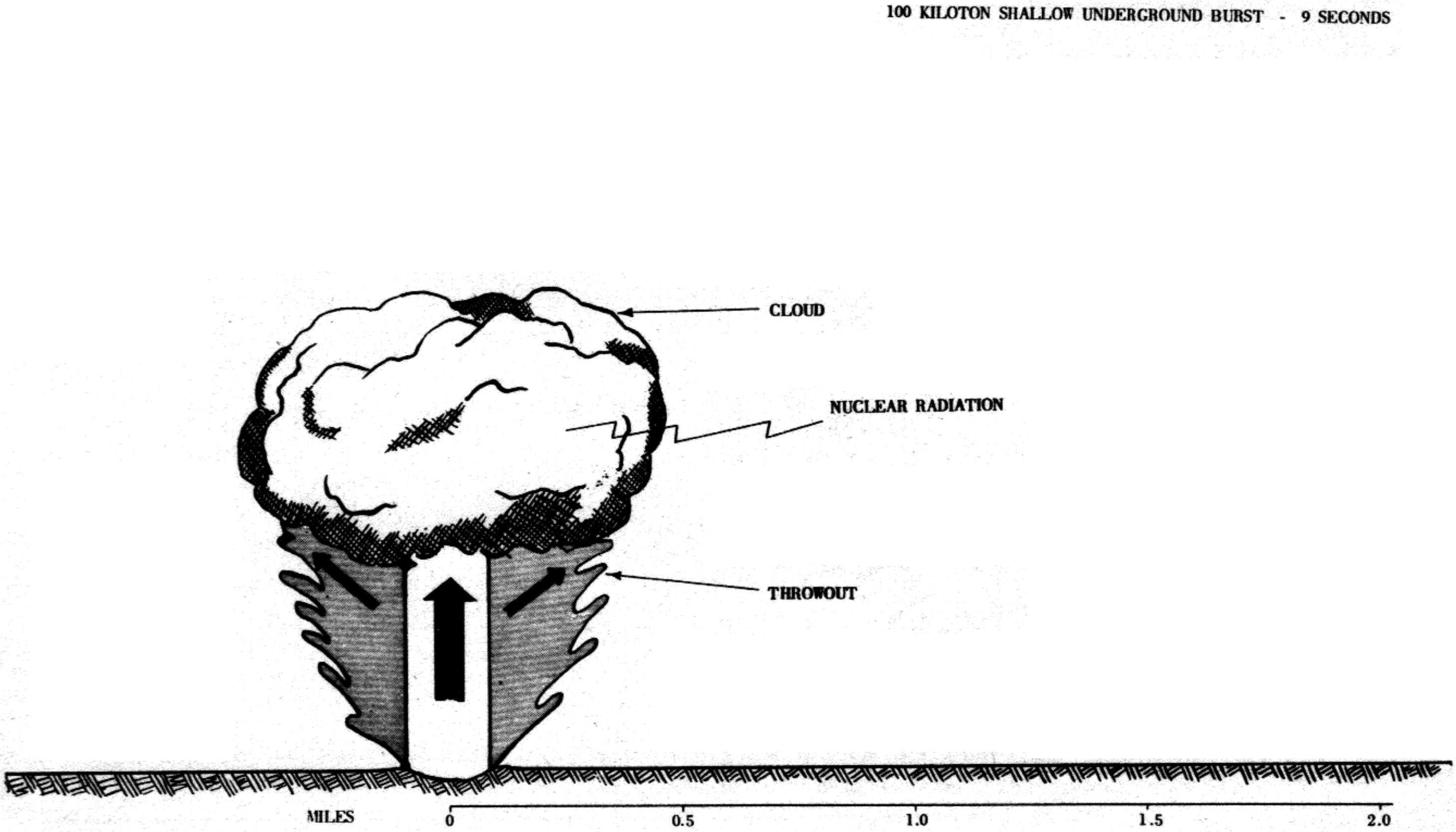

Figure 2.75b. Chronological development of a 100-kiloton shallow underground burst: 9.0 seconds after detonation.

The atomic cloud continues to rise, giving off intense nuclear radiations which are still a hazard on the ground at 9 seconds after the detonation. At this time, the larger pieces of rock and debris in the throw-out begin to descend to earth.

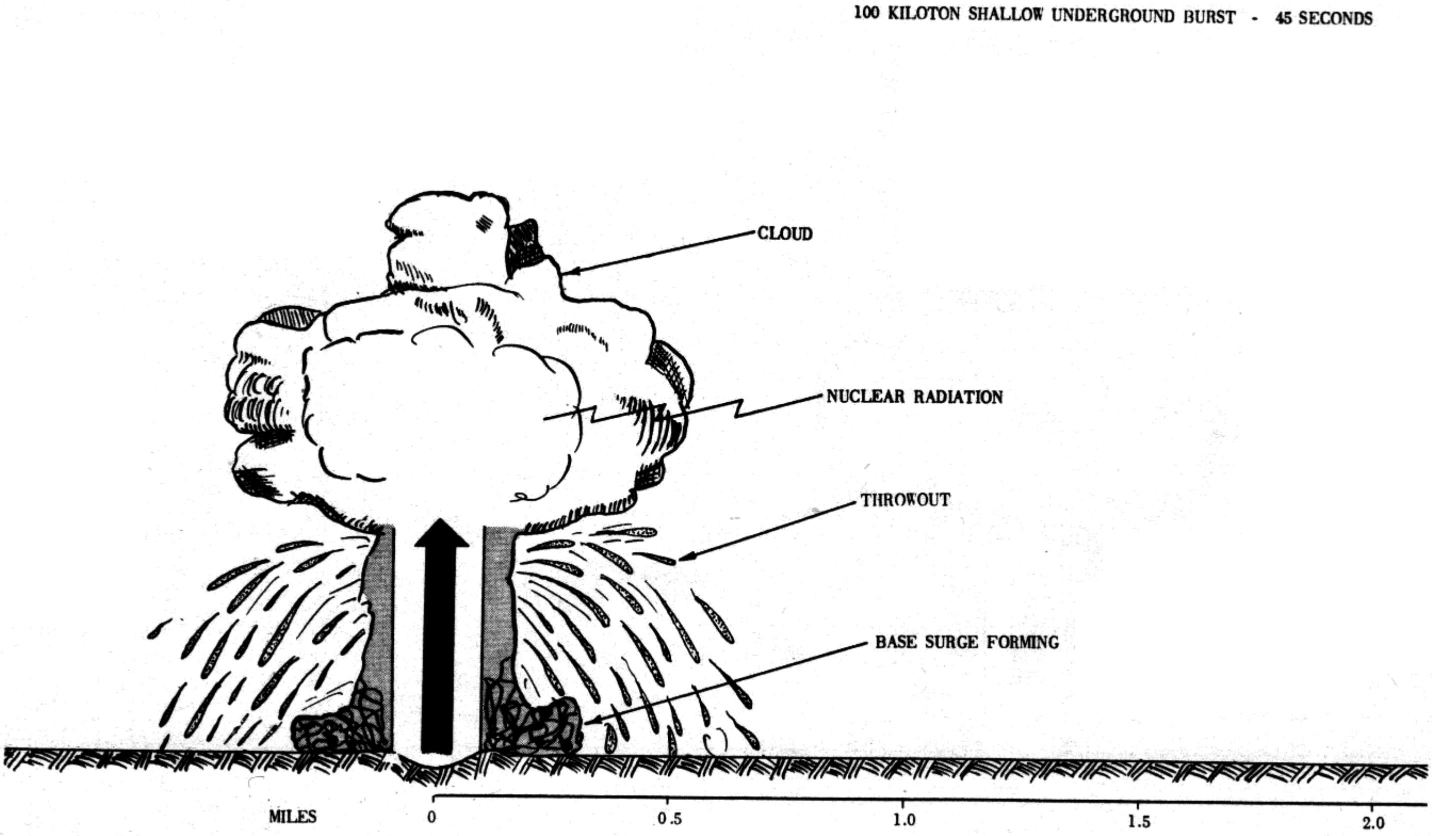

Figure 2.75c. Chronological development of a 100-kiloton shallow underground burst: 45 seconds after detonation.

As the material from the column descends, the finer soil particles attain a high velocity and upon reaching the ground they spread out rapidly to form a base surge similar to that in an underwater explosion. The extent of the base surge, which is likely to be radioactive, depends upon many factors, including the energy yield of the explosion, the depth of burst, and the nature of the soil. It is believed that a dry sandy terrain will be particularly conducive to base surge formation.

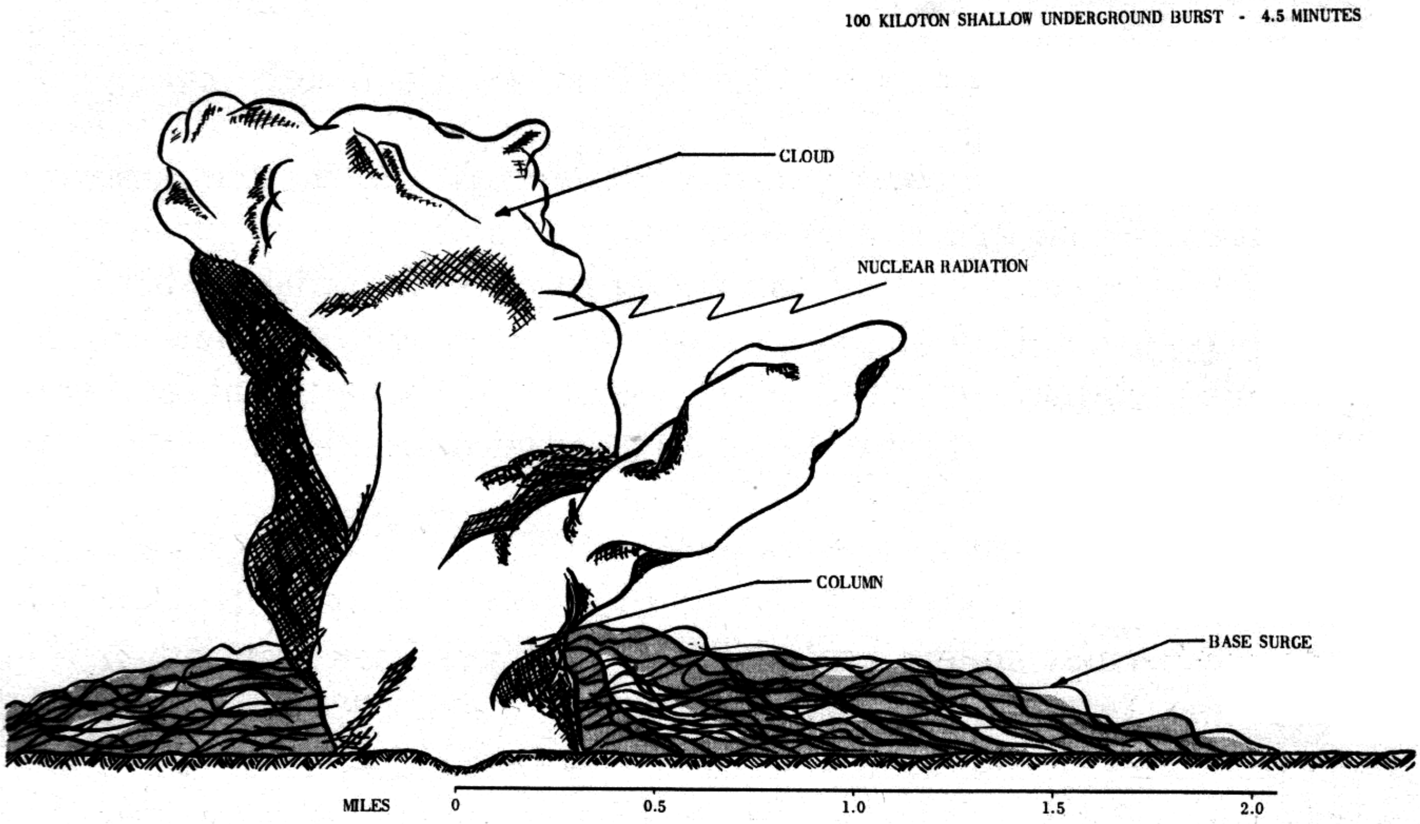

Figure 2.75d. Chronological development of a 100-kiloton shallow underground burst: 4.5 minutes after detonation.

The base surge increases in height and area and soon begins to merge with the atomic cloud of bomb residues, etc., part of which descends and spreads out under the influence of the prevailing winds. In due course, the radioactive clouds disperse, but the contaminated particles descend to earth to produce a hazardous fallout over a large area, especially in the downwind direction, during the course of a few hours.

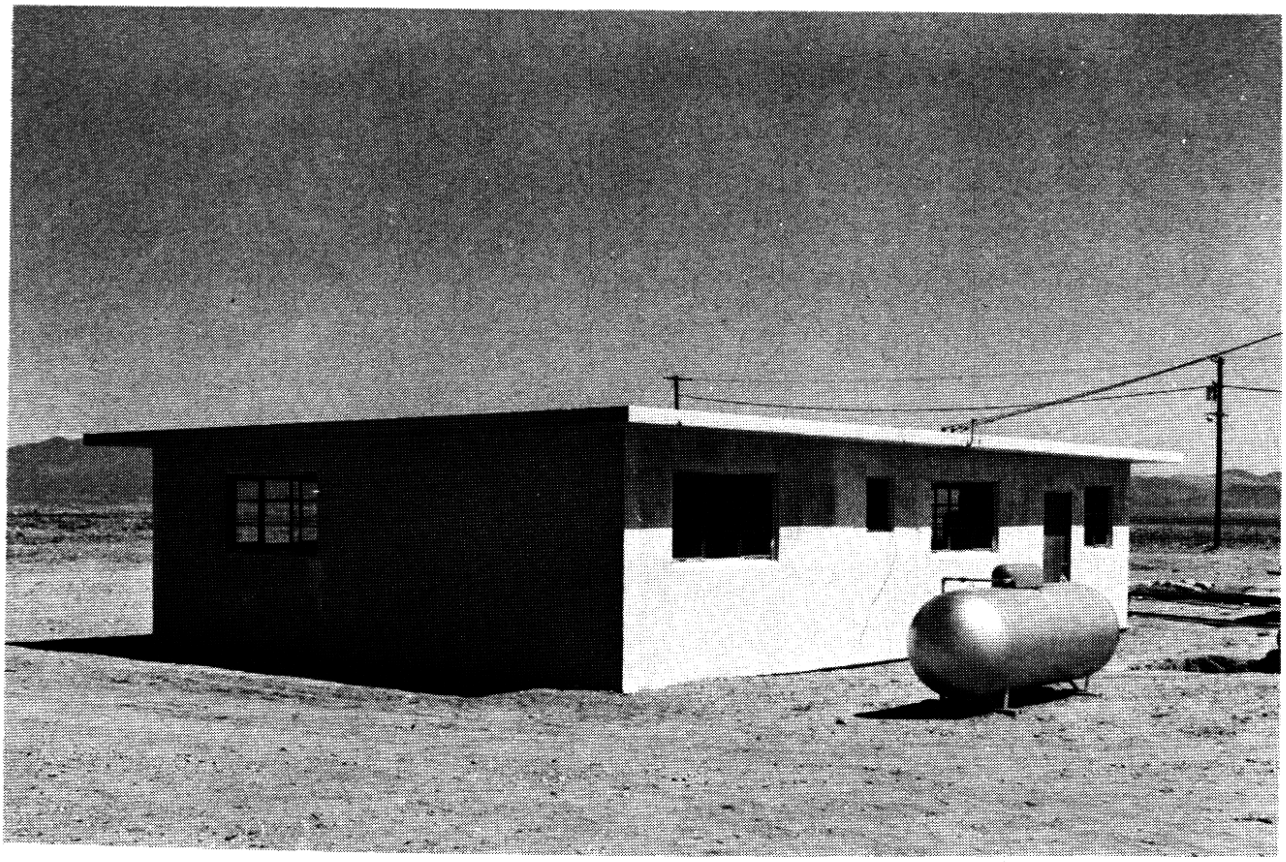

Figure 4.37. Reinforced precast concrete house before a nuclear explosion, Nevada Test Site.

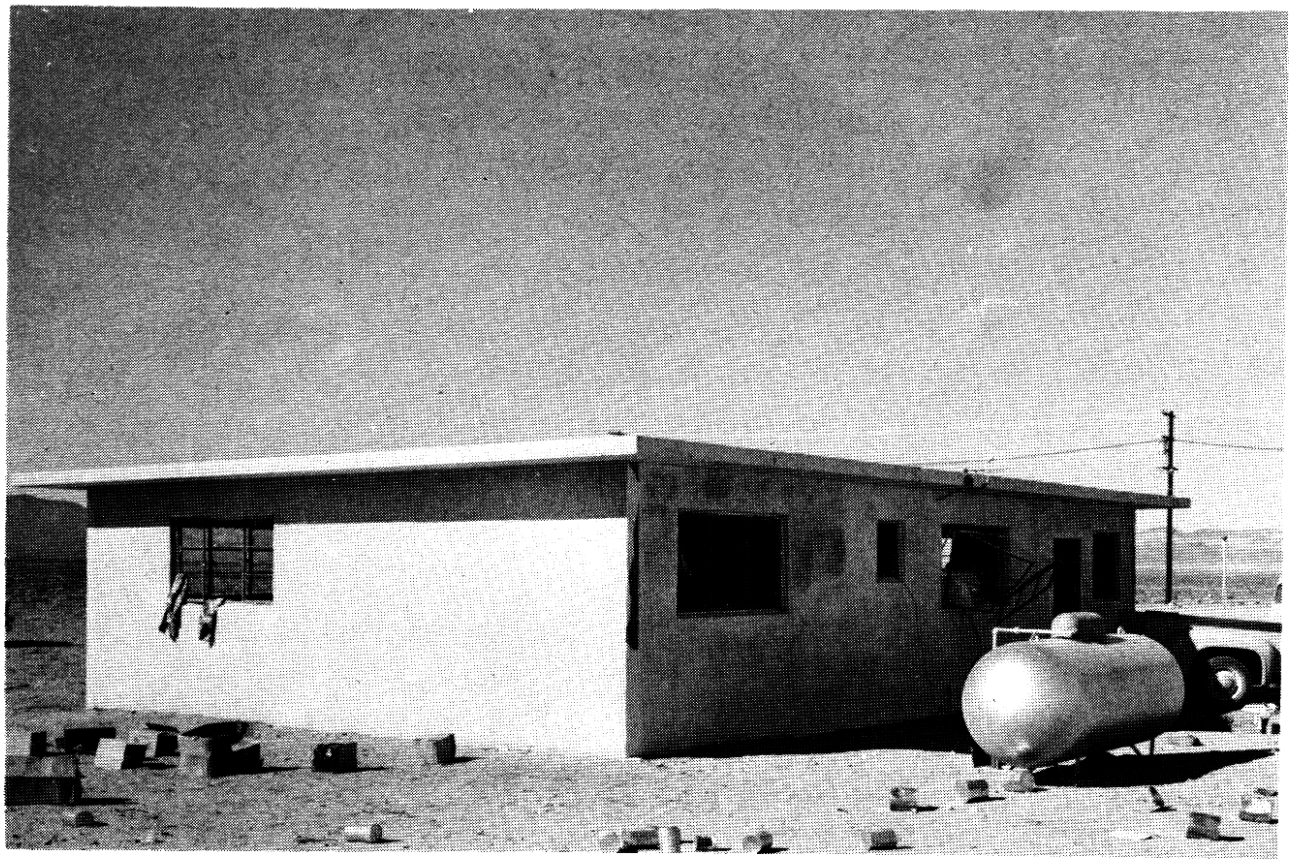

Figure 4.38. Reinforced precast concrete house after the nuclear explosion (5 psi overpressure). The LP-gas tank, sheltered by the house, is essentially undamaged.

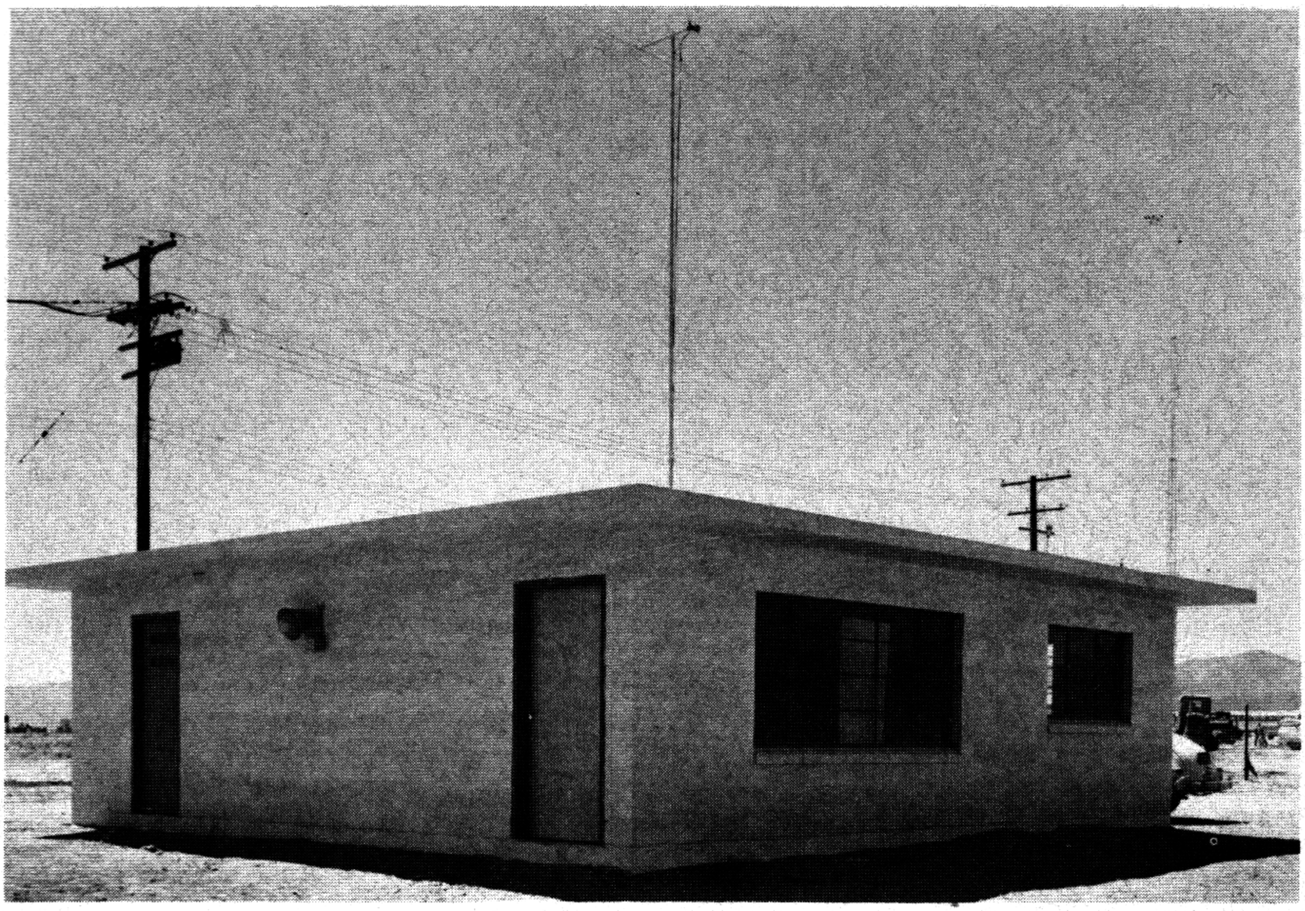

Figure 4.41. Reinforced masonry-block house before a nuclear explosion, Nevada Test Site.

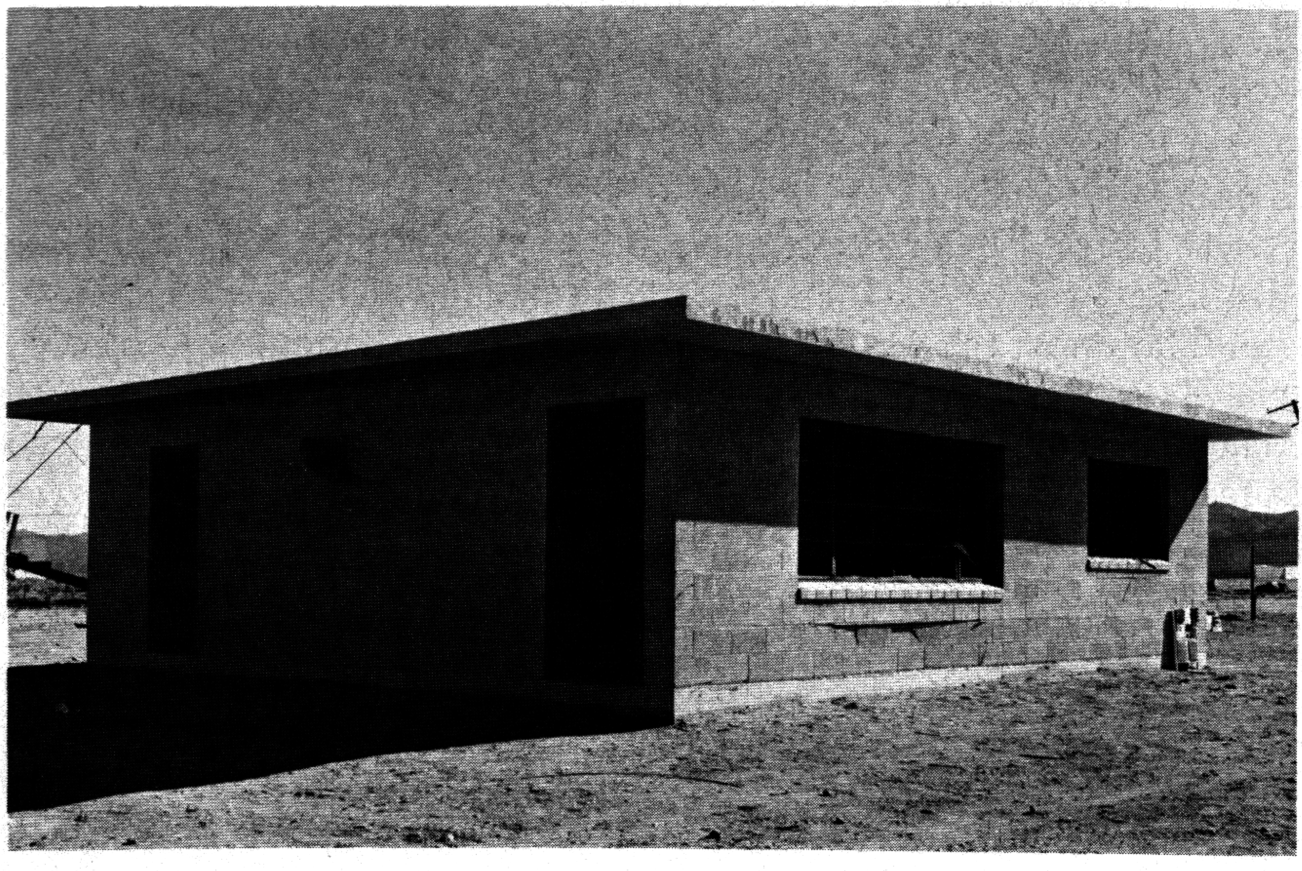

Figure 4.42. Reinforced masonry-block house after the nuclear explosion (5 psi overpressure).

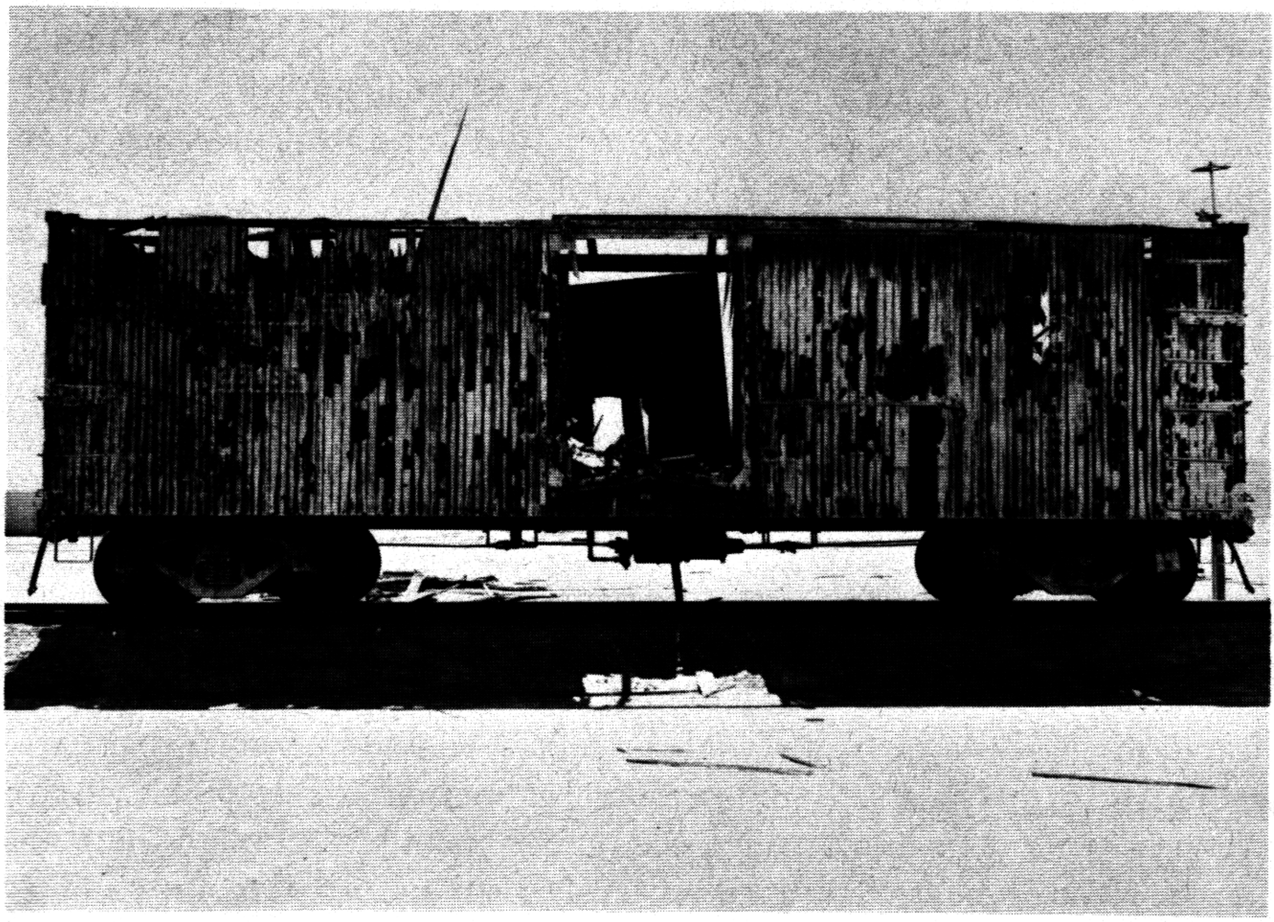

Figure 4.97a. Loaded wooden boxcar after a nuclear explosion (4 psi overpressure).

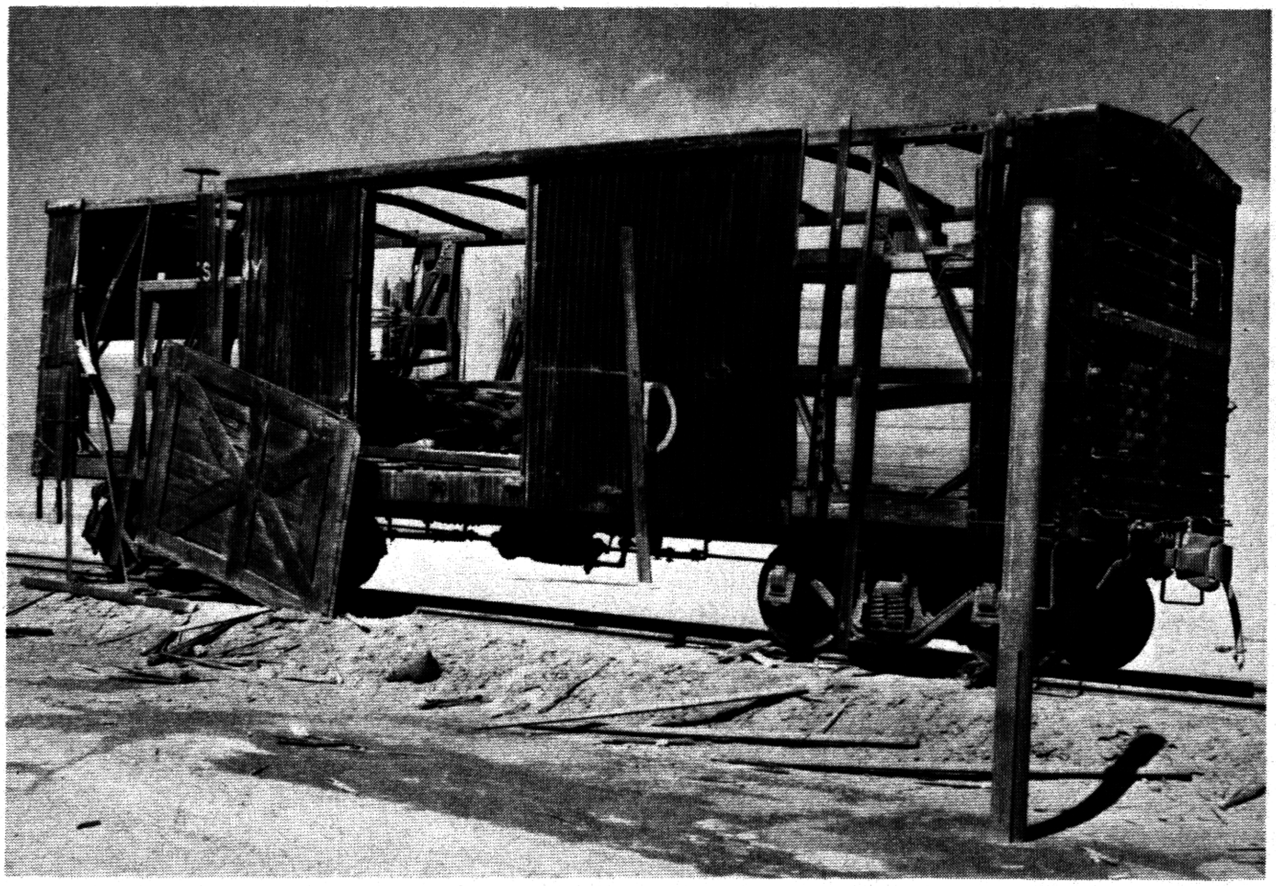

Figure 4.97b. Loaded wooden boxcar after a nuclear explosion (6 psi overpressure).

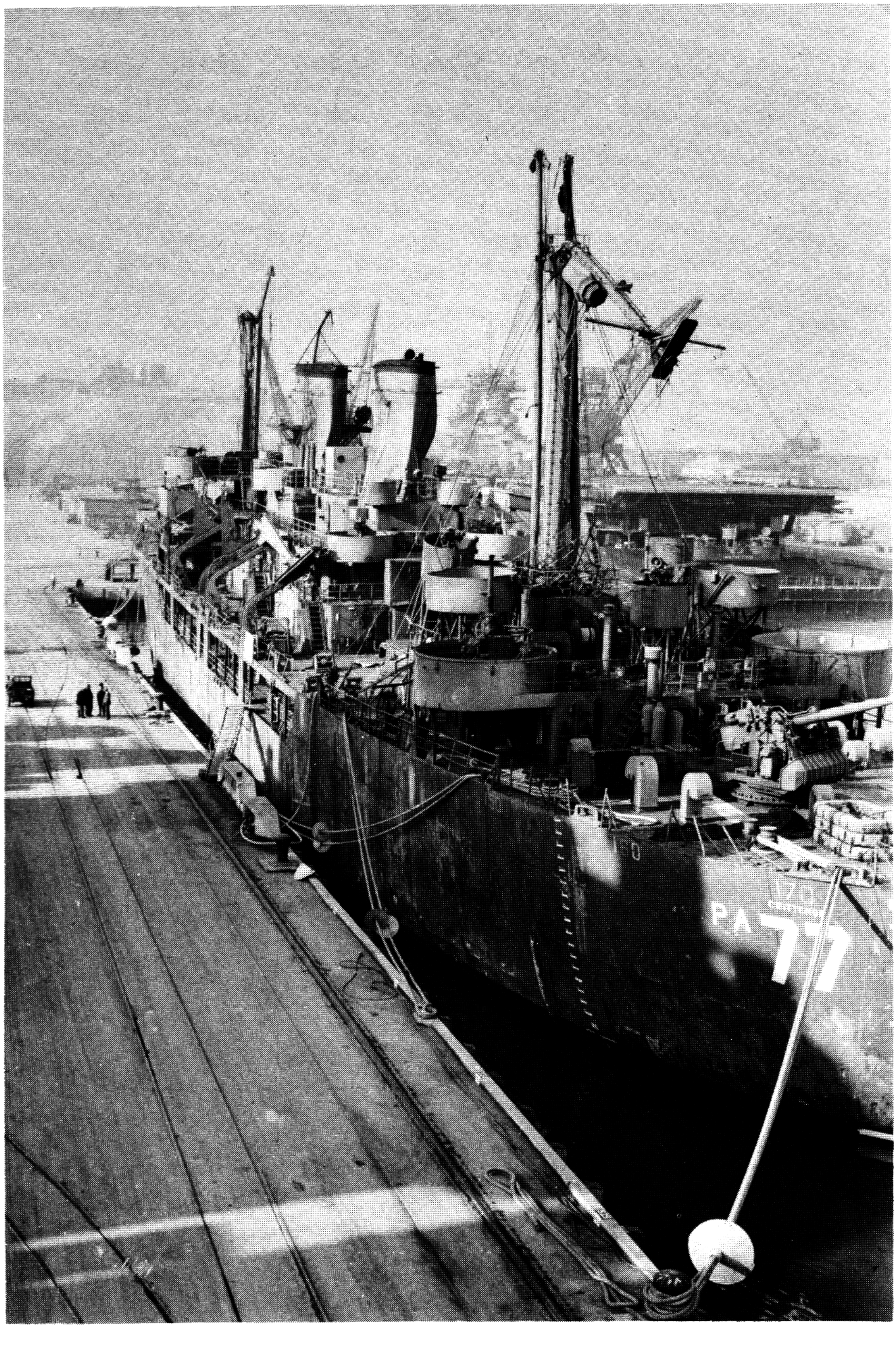

Figure 4.101a. The U. S. S. Crittenden after ABLE test; damage resulting was generally moderate (0.47 mile from surface zero).

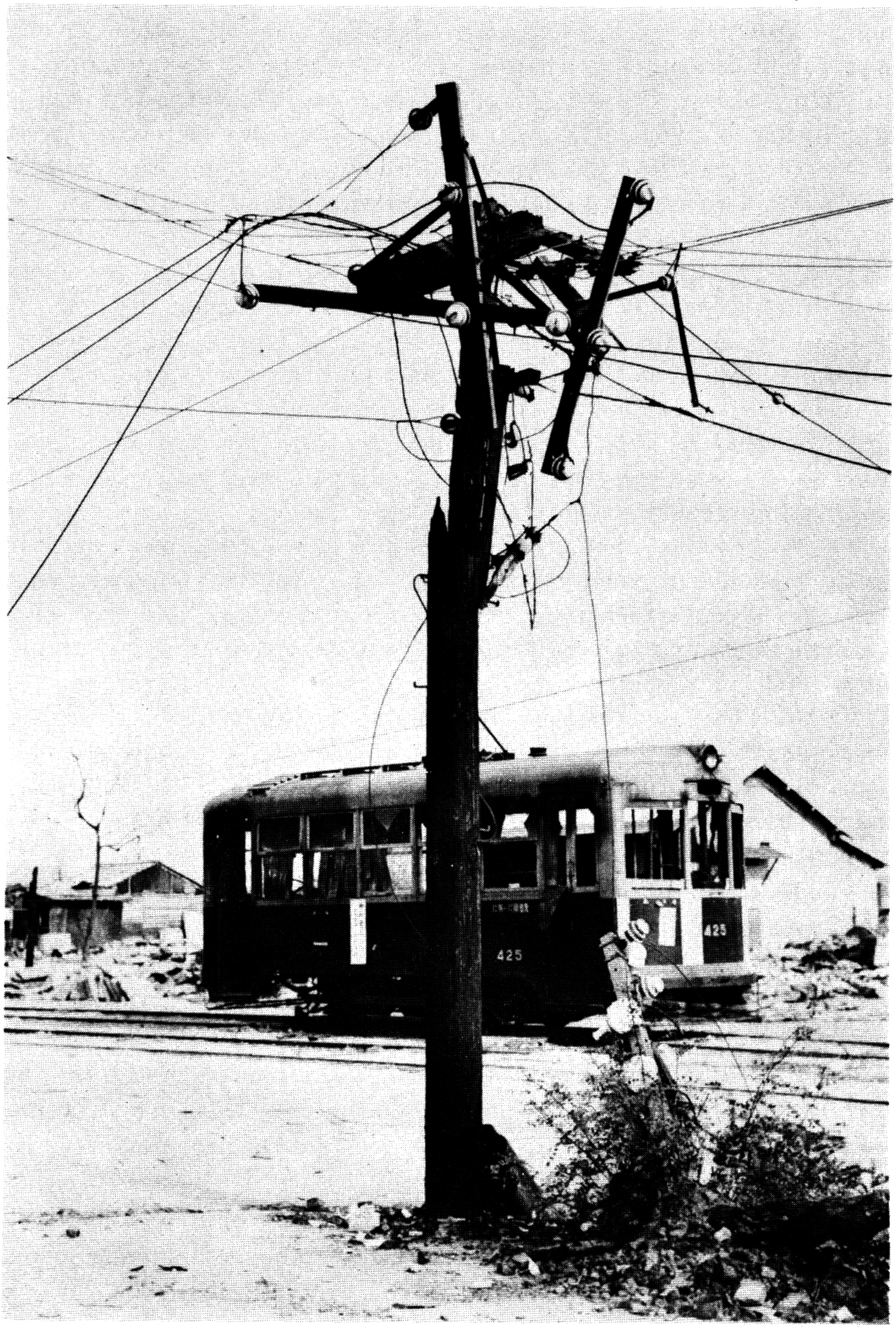

Figure 4.105. Damage to utility pole (0.80 mile from ground zero at Hiroshima).

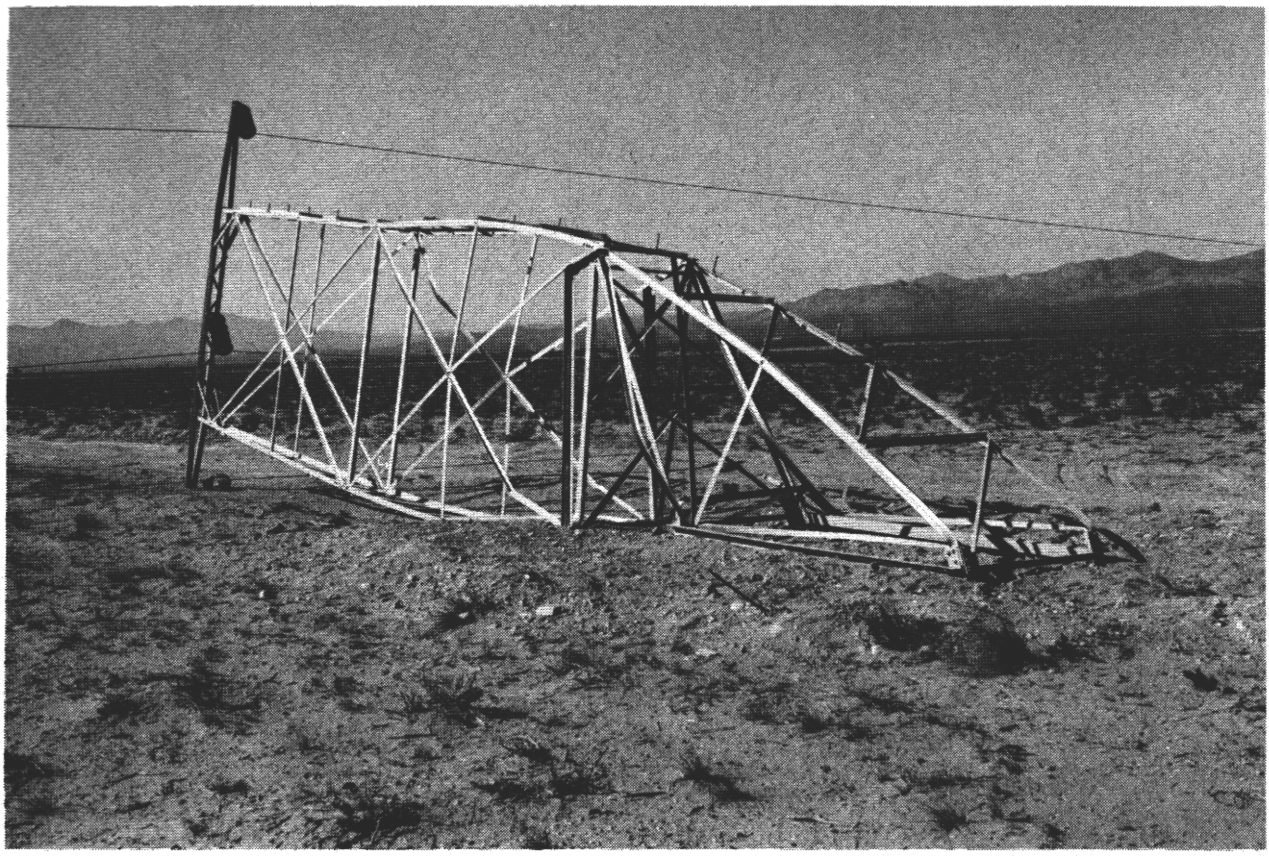

Figure 4.109a. Collapsed suspension tower (5 psi overpressure from 30-kiloton explosion, Nevada Test Site).

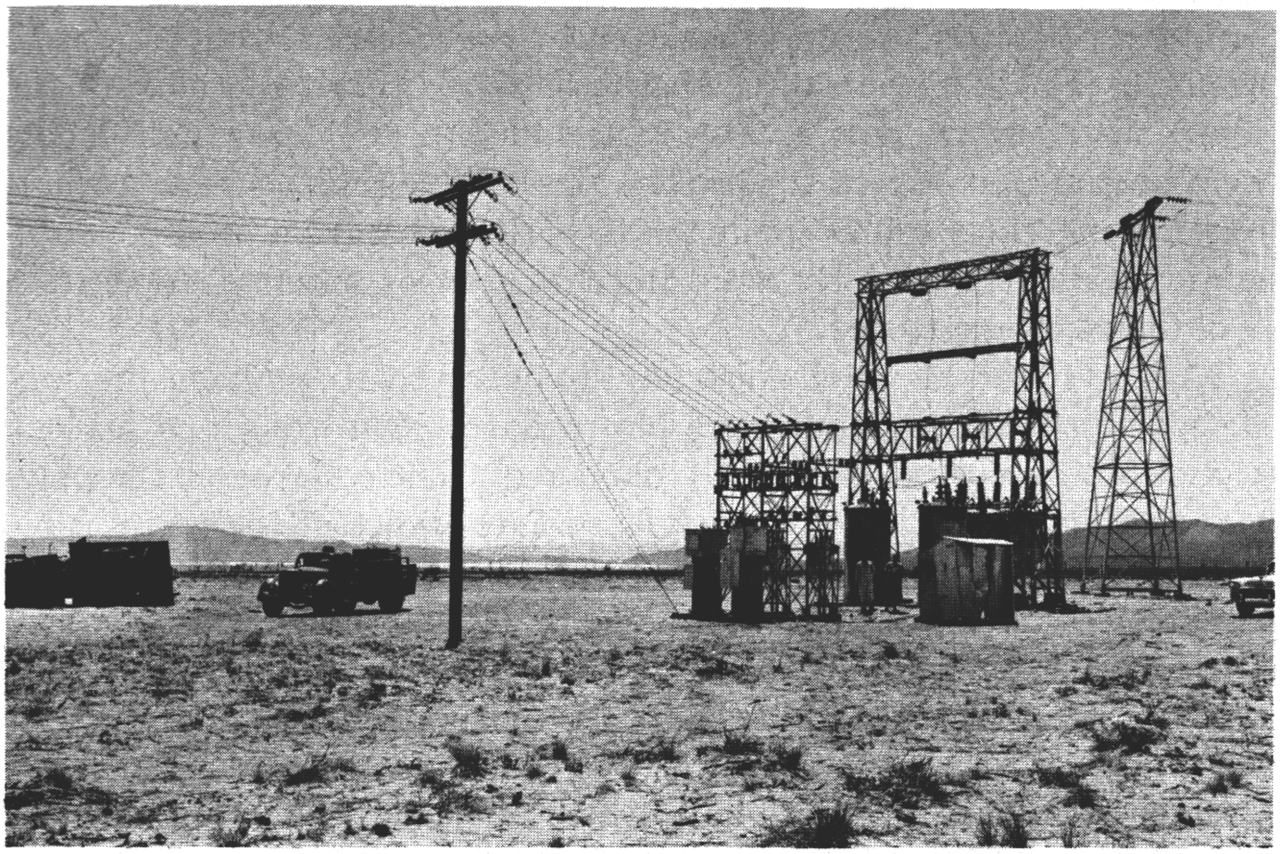

Figure 4.109b. Dead-end tower, suspension tower, and transformers (5 psi overpressure from 30-kiloton explosion, Nevada Test Site).

TABLE 6.23

DAMAGE CRITERIA FOR TRANSMITTING TOWERS

Damage class	Nature of damage
A and B	Towers demolished or flat on the ground (Fig. 4.109a).
C	Towers partially buckled, but held by guy lines; ineffective for transmission.
D	Guy lines somewhat slack, but tower able to transmit (Fig. 4.109b).

DAMAGE TO FORESTS

6.24 In considering damage to forests, the discussion will refer more specifically to naturally occurring broadleaf and coniferous stands averaging about 175 trees per acre. Because trees are primarily sensitive to drag forces, the zone in which the damage decreases from class A to class D is relatively narrow. In particular, the transition from A to B is difficult to delineate, and so these two types of damage are taken together. The different classifications are described in Table 6.24. Since the effect of air blast on forests is similar to that of strong

Figure 6.24a. Forest stand after a nuclear explosion, B damage (3.8 psi overpressure).

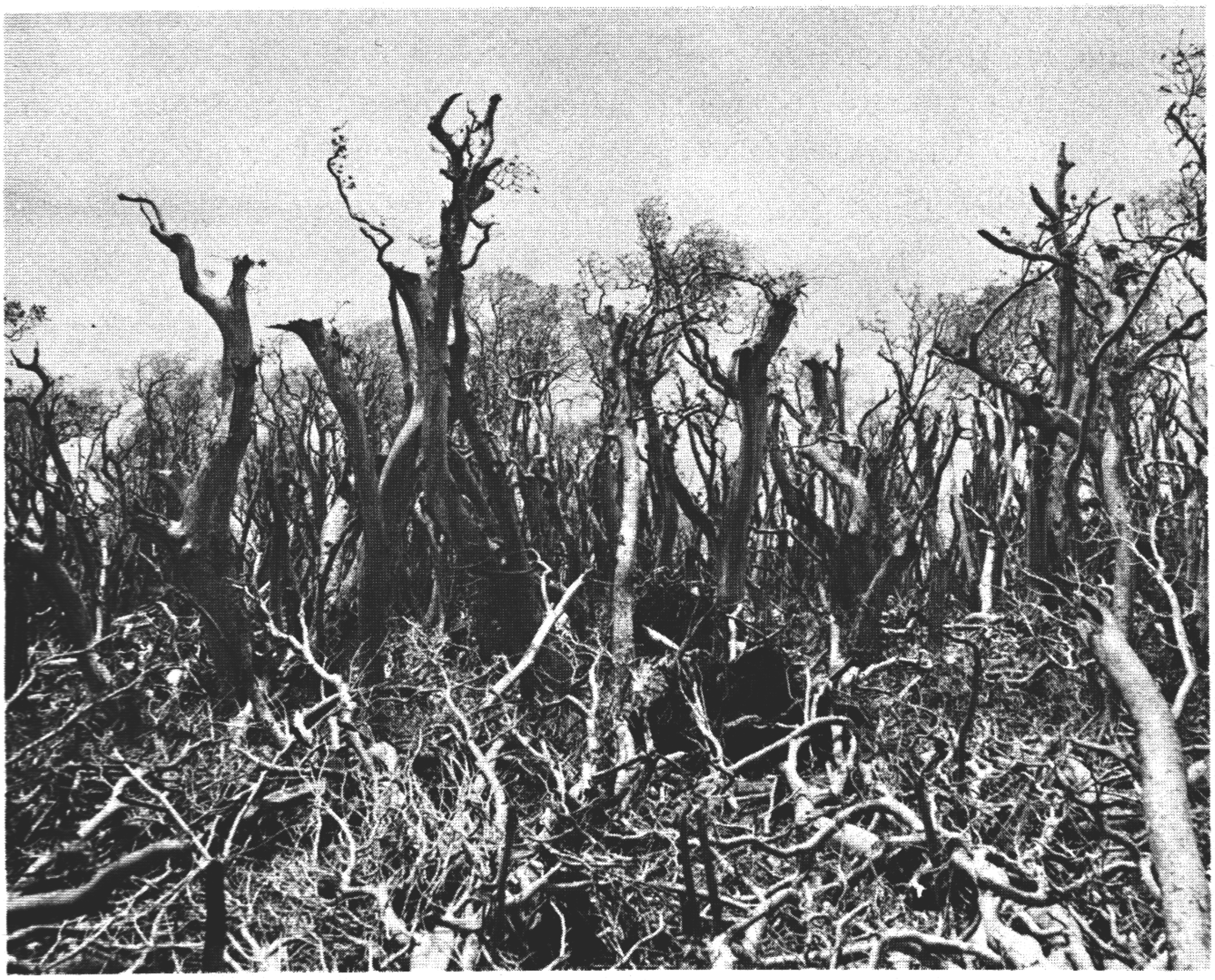

Figure 6.24b. Forest stand after a nuclear explosion, C damage (2.4 psi overpressure).

TABLE 6.24

DAMAGE CRITERIA FOR FORESTS

Damage class	Nature of damage	Equivalent hurricane wind velocity (miles per hour)
A & B	Up to 90 percent of trees blown down; remainder denuded of branches and leaves (Fig. 6.24a). (Area impassable to vehicles and very difficult on foot.)	130–140
C	About 30 percent of trees blown down; remainder have some branches and leaves blown off (Fig. 6.24b). (Area passable to vehicles only after extensive clearing.)	90–100
D	Very few trees blown down; some leaves and branches blown off. (Area passable to vehicles.)	60–80

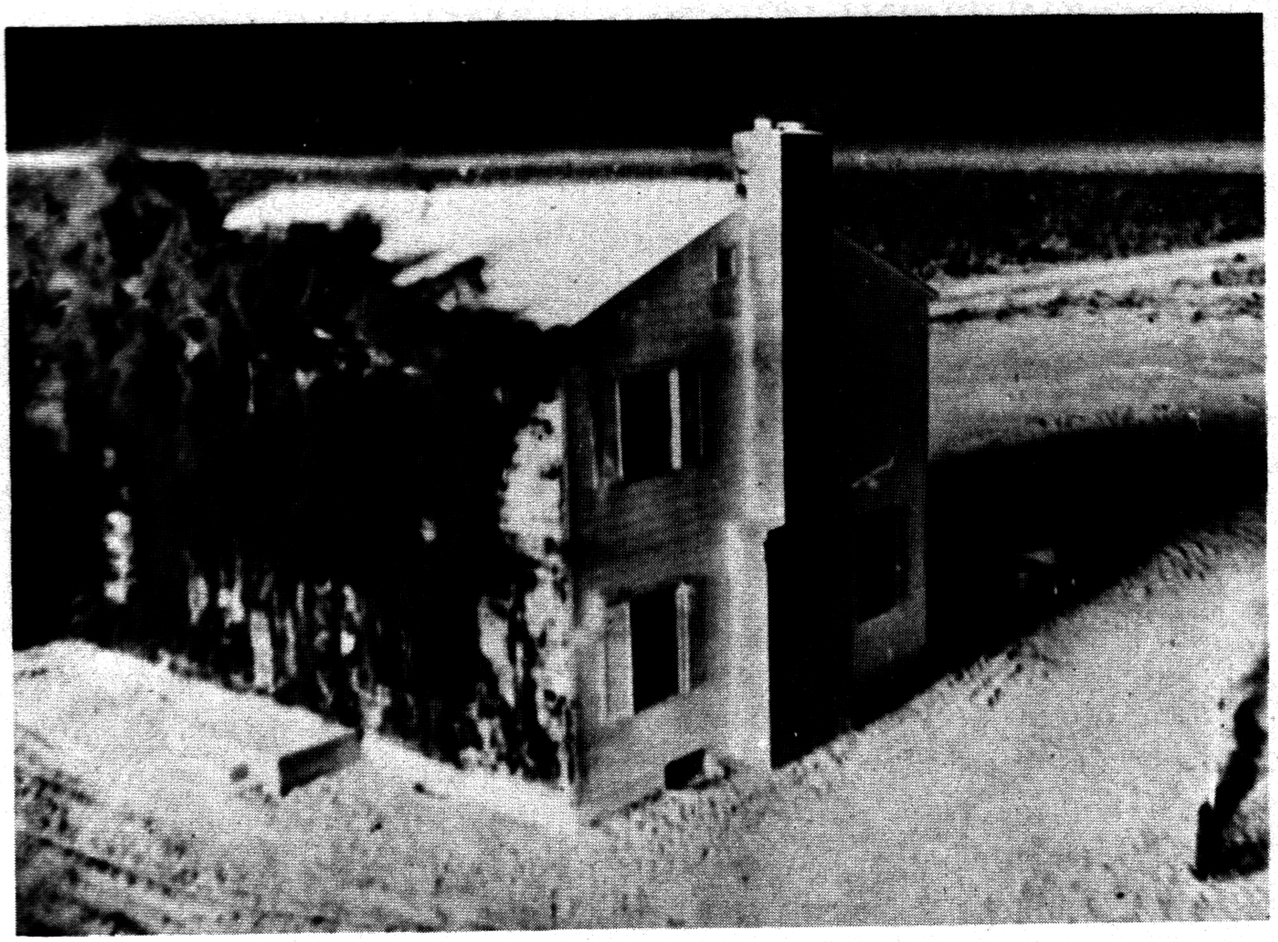

Figure 7.34a. Thermal effects on wood frame house almost immediately after explosion (about 25 cal/sq cm).

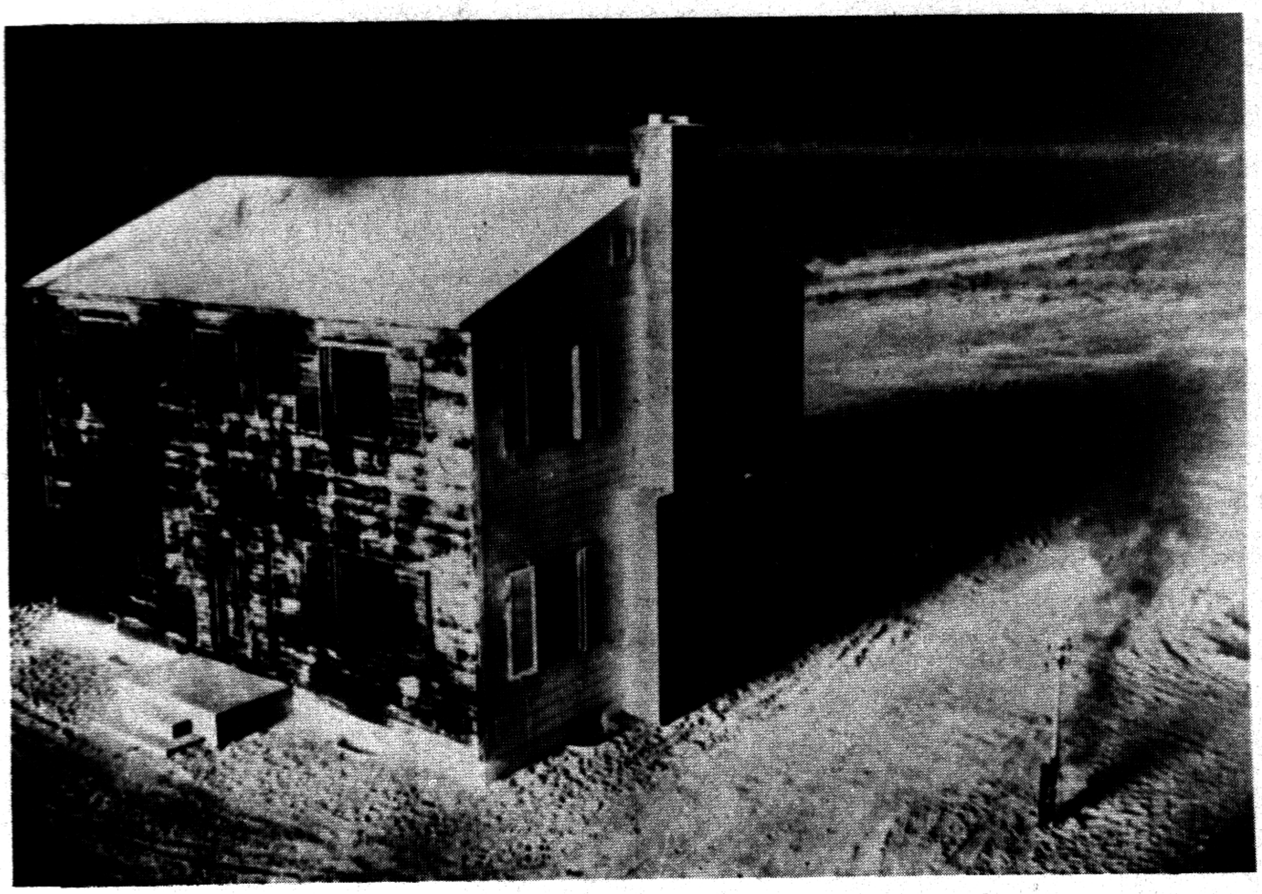

Figure 7.34b. Thermal effects on wood frame house 2 seconds later.

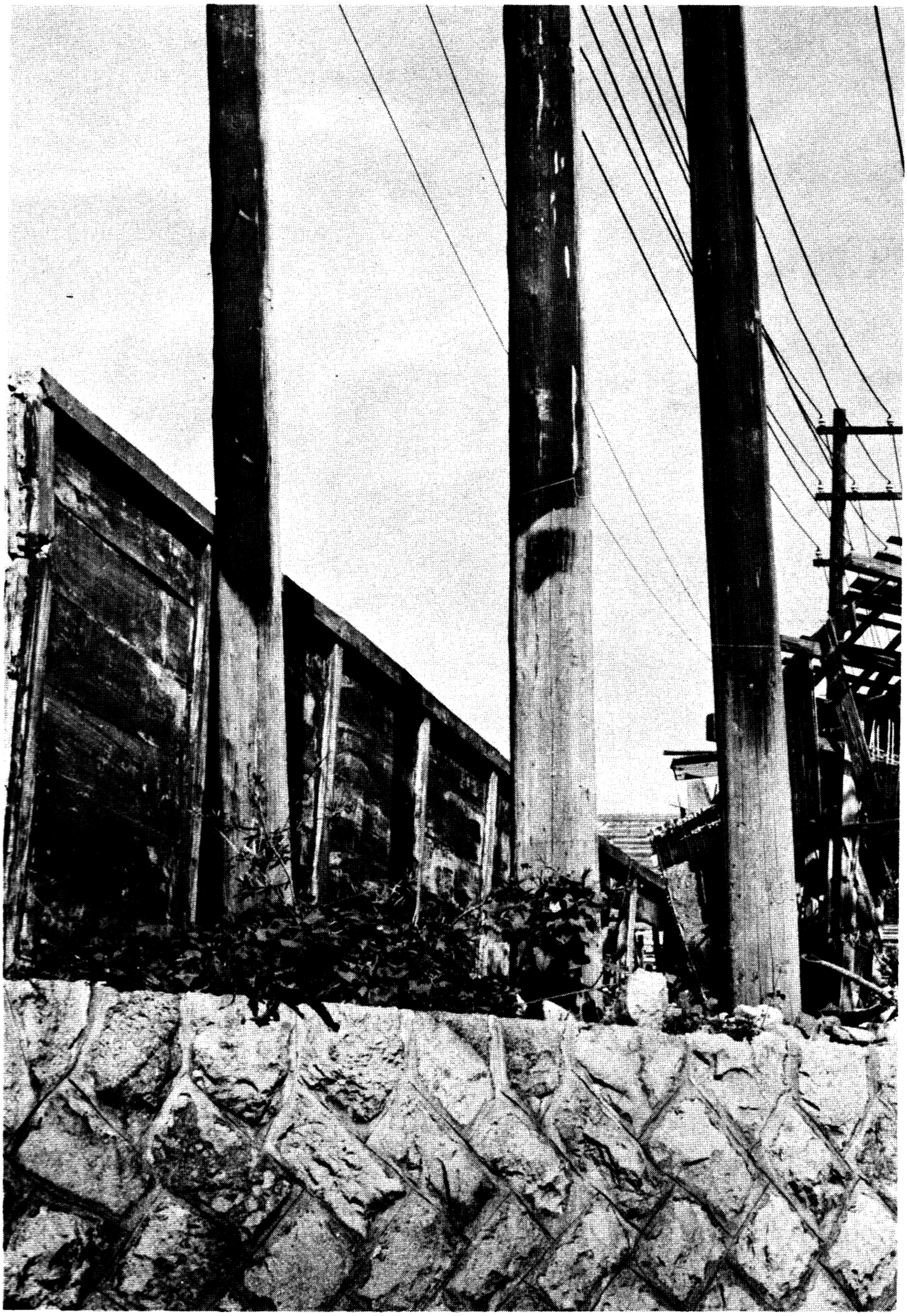

Figure 7.73b. Flash burns on wooden poles (1.17 miles from ground zero at Nagasaki). The uncharred portions were protected from thermal radiation by a fence.

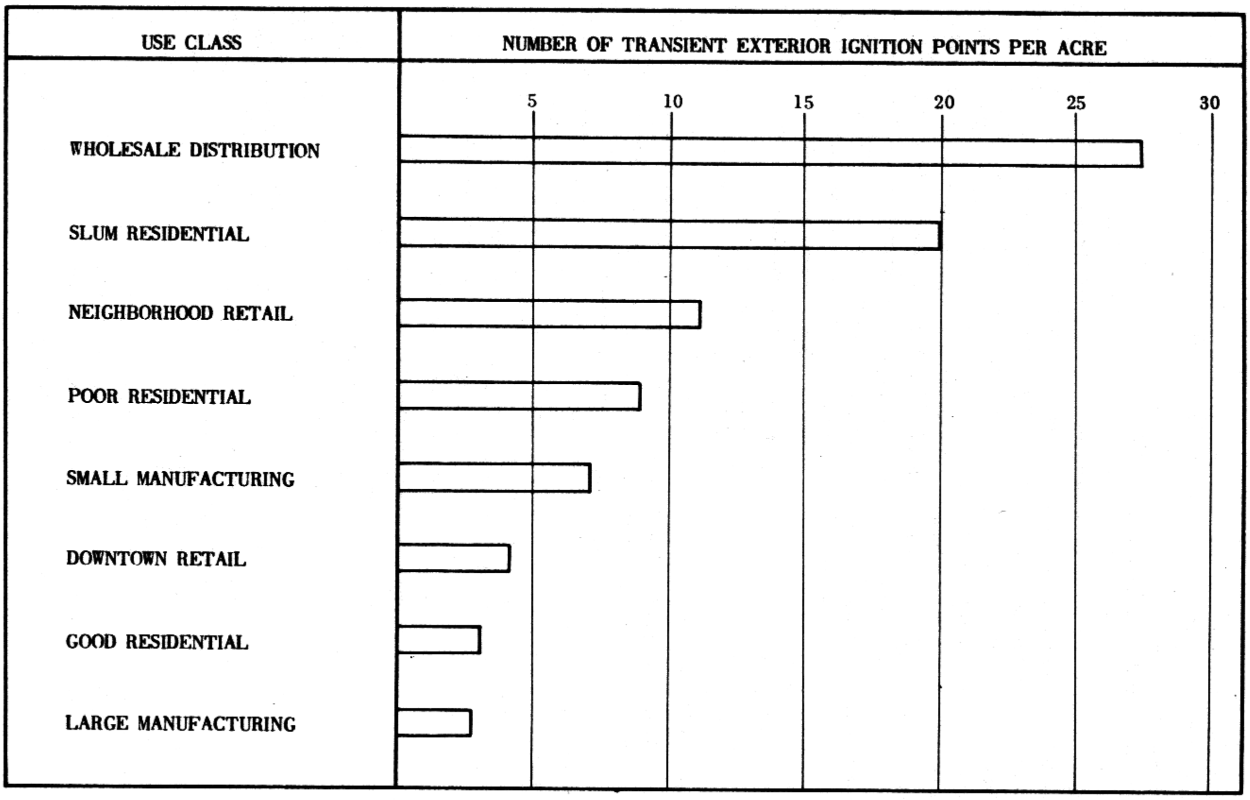

Figure 7.80. **Frequency of exterior ignition points for various areas in a city.**

number of large cities in the United States. It is seen that the density of ignition points is greatest in wholesale distribution and slum residential areas, and is least in good residential and large manufacturing areas.[5] Paper was the commonest ignitable material found everywhere except in downtown retail areas where awnings represented the major source of fire.

7.81 The density of ignition points provides some indication of the chance of fires being started under ideal weather conditions. But the results in Fig. 7.80 are by themselves not sufficient to permit an estimate to be made of the number of significant fires that will actually result. In the first place, at locations closer to ground zero, where the thermal energy exceeds about 12 calories per square centimeter, almost all the ignitable materials will actually flame (Table 7.65). On the other hand, at greater distances, only those most easily ignitable will catch fire. Further, the formation of a significant fire, capable of spreading, will require appreciable quantities of combustible material close by, and this may not always be available.

7.82 The fact that accumulations of ignitable trash close to a wooden structure represent a real fire hazard was demonstrated at the nuclear tests carried out in Nevada in 1953. In these tests, three miniature wooden houses, each having a yard enclosed with a wooden

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[5] The area types are in accordance with the classification used by the U. S. Bureau of Census.

fence, were exposed to 12 calories per square centimeter of thermal radiation. One house, at the left of Fig. 7.82, had weathered siding showing considerable decay, but the yard was free from trash. The next house also had a clean yard and, further, the exterior siding was well maintained and painted. In the third house, at the right of the photograph, the siding, which was poorly maintained, was weathered, and the yard was littered with trash.

7.83. The state of the three houses after the explosion is seen in Fig. 7.83. The third house, at the right, soon burst into flame and was burned to the ground. The first house, on the left, did ignite but it did not burst into flame for 15 minutes. The well maintained house in the center with the clean yard suffered scorching only. It is of interest to recall that the wood of a newly erected white-painted house exposed to about 25 calories per square centimeter was badly charred but did not ignite (Fig. 7.34b).

7.84 The value of fire-resistive furnishing in decreasing the number of ignition points was also demonstrated in the 1953 tests. Two identical, sturdily constructed houses, each having a window 4 feet by 6 feet facing the point of burst, were erected where the thermal radiation exposure was 17 calories per square centimeter. One of the houses contained rayon drapery, cotton rugs, and clothing, and, as was expected, it burst into flame immediately after the explosion and burned completely. In the other house, the draperies were of vinyl plastic, and rugs and clothing were made of wool. Although more ignition occurred, the recovery party, entering an hour after the explosion, was able to extinguish fires.

7.85 There is another point in connection with the initiation of fires by thermal radiation that needs consideration. This is the possibility that the flame resulting from the ignition of a combustible material may be subsequently extinguished by the blast wind. It was thought that there was evidence for such an effect from an observation made in Japan (§ 7.92), but this may have been an exceptional case. The matter has been studied, both in connection with the effects in Japan and at various nuclear tests, and the general conclusion is that the blast wind has no significant effect in extinguishing fires (see § 7.93).

SPREAD OF FIRES

7.86 The spread of fires in a city, depends upon a variety of conditions, e. g., weather, terrain, and closeness and combustibility of the buildings. A detailed review of large-scale fires has shown, however, that if other circumstances are more-or-less the same, the most

Figure 7.82. Wooden test houses before exposure to a nuclear explosion, Nevada Test Site.

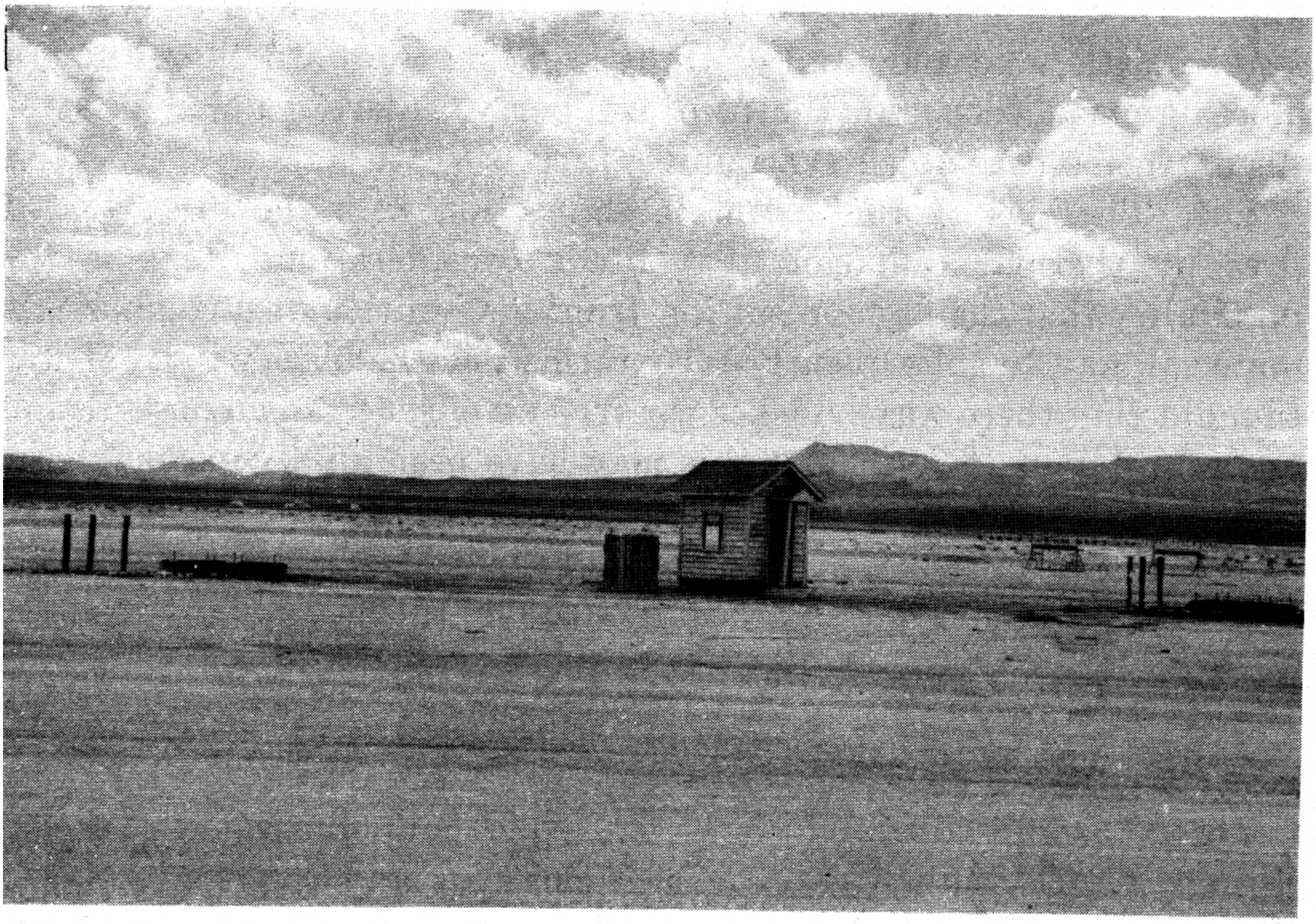

Figure 7.83. Wooden test houses after exposure to the nuclear explosion.

important criterion of the probability of fire spread is the distance between buildings. It is evident, from general considerations, that the lower the building density or "built-upness" of an area, the less will be the probability that fire will spread from one structure to another. Further, the larger the spaces between buildings the greater the chances that the fire can be extinguished.

7.87 The curve in Fig. 7.87 gives a rough idea of how the probability of fire spread, expressed as a percentage, depends upon the average distance between buildings in a city. The results will be dependent, to some extent, upon the types of structures involved, e. g., whether they are fire-resistive or not, as well as upon the damage caused by the blast wave (§ 7.79). It should be noted that Fig. 7.87 applies to fire spread accompanying a nuclear explosion, when a large number of small fires are started directly by thermal radiation and indirectly in other ways.

7.88 Another aspect of fire spread is the development of mass fires in a forest following primary ignition of dried leaves, grass, and rotten wood by the thermal radiation. Some of the factors which will influence the growth of such fires are the moisture content of the trees,

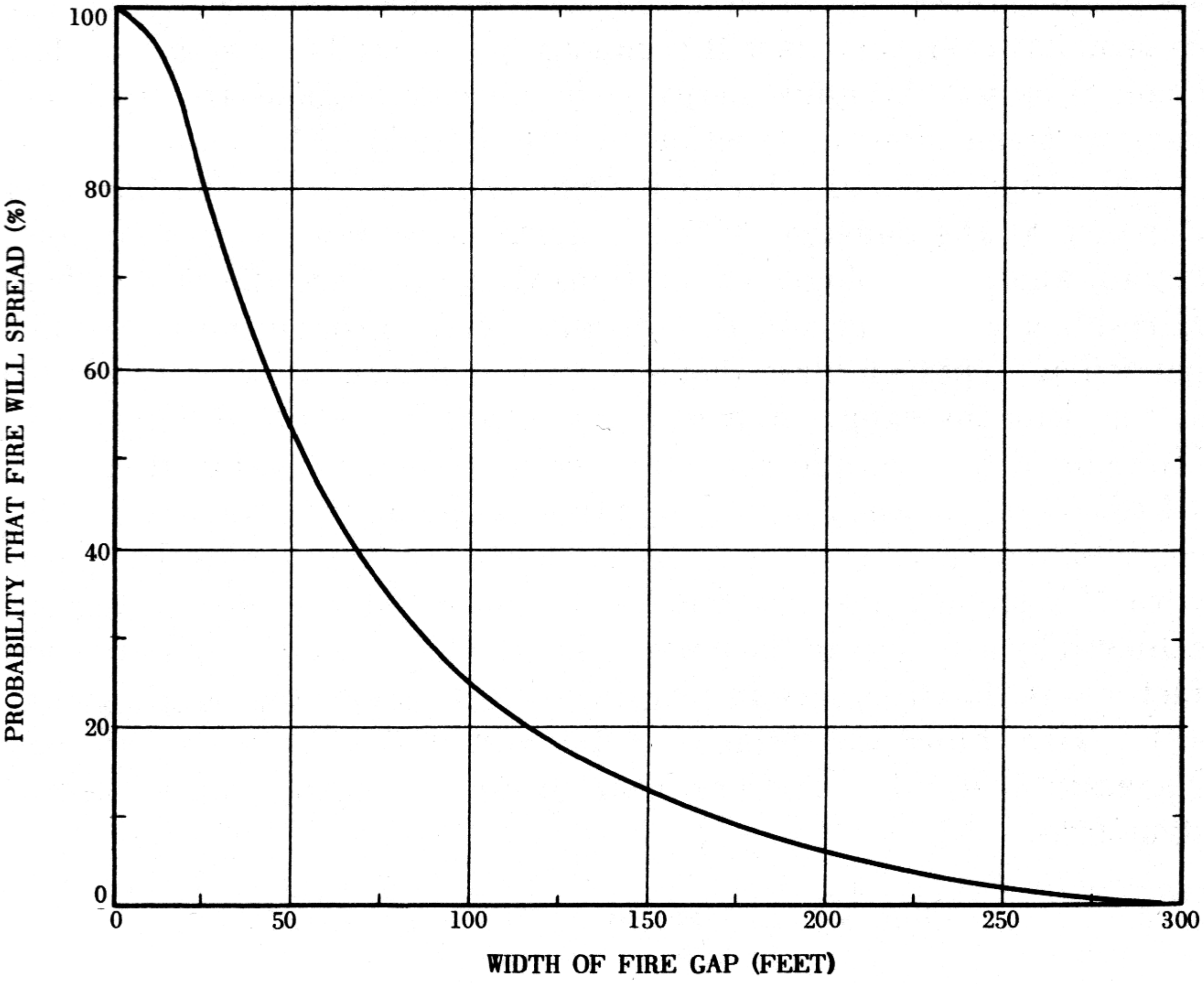

Figure 7.87. Width of gap and probability of fire spread.

topography, and meteorological conditions. Low atmospheric humidity, strong winds, and steep terrain favor the development of forest fires. In general, a deciduous forest, particularly when in leaf, may be expected to burn less rapidly and with less intensity than a forest of coniferous trees. Green leaves and the trunks of trees would act as shields against thermal radiation, so that the number of points at which ignition occurs in a forest may well be less than would appear at first sight.

INCENDIARY EFFECTS IN JAPAN

The Nuclear Bomb as an Incendiary Weapon

7.89 The incendiary effects of a nuclear explosion do not present any especially characteristic features. In principle, the same over-all result, as regards destruction by fire and blast, might be achieved by the use of conventional incendiary and high-explosive bombs. It has been estimated, for example, that the fire damage to buildings and other structures suffered at Hiroshima could have been produced by about 1,000 tons of incendiary bombs distributed over the city. It can be seen, however, that since this damage was caused by a single nuclear bomb of only 20 kilotons energy yield, nuclear weapons are capable of causing tremendous destruction by fire, as well as by blast.

7.90 Evidence was obtained from the nuclear explosions over Japan that the damage by fire is much more dependent upon local terrain and meteorological conditions than are blast effects. At both Hiroshima and Nagasaki the distances from ground zero at which particular types of blast damage were experienced were much the same. But the range of incendiary effects was quite different. In Hiroshima, for example, the total area severely damaged by fire, about 4.4 square miles, was roughly four times as great as in Nagasaki. One contributory cause was the irregular layout of Nagasaki as compared with Hiroshima; also greater destruction could probably have been achieved by a change in the point of burst. Nevertheless, an important factor was the difference in terrain, with its associated building density. Hiroshima was relatively flat and highly built up, whereas Nagasaki had hilly portions near ground zero that were bare of structures.

Origin and Spread of Fires in Japan

7.91 Definite evidence was obtained from Japanese observers that the thermal radiation caused thin, dark cotton cloth, such as the black-out curtains that were in common use during the war, thin paper, and dry, rotted wood to catch fire at distances up to 3,500 feet (0.66 mile) from ground zero (about 35 calories per square centimeter). It was reported that a cedar bark roof farther out was seen to burst into flame, apparently spontaneously, but this was not definitely confirmed. Abnormal enhanced amounts of radiation, due to reflection, scattering, and focusing effects, might have caused fires to originate at isolated points (Fig. 7.91).

7.92 Interesting evidence of the ignition of sound wood was found about a mile from ground zero at Nagasaki, where the thermal energy was approximately 15 calories per square centimeter. A light piece of wood, similar to the flat side of an orange crate, had its front surface charred. In addition, however, blackening was observed through cracks and nail holes, where the thermal radiation would not have penetrated, and also around the edges adjoining the charred surface. A possible explanation is that the exposed surface of the wood had actually ignited, due to the heat from the thermal radiation, and the flames had spread through the cracks and holes around the edges for several seconds, before they were extinguished by the blast wind.

7.93 From the evidence of charred wood found at both Hiroshima and Nagasaki, it was originally concluded that such wood had actually been ignited by thermal radiation and that the flames were subsequently extinguished by the blast. But it now seems more probable that, apart from some exceptional instances, such as that just described, there was no actual ignition of the wood. The absorption of the thermal radiation caused charring in sound wood but the temperatures were generally not high enough for ignition to occur (§ 7.34). Rotted and checked wood and excelsior, however, have been known to burn completely, and the flame is not greatly affected by the blast wave.

7.94 It is not known to what extent thermal radiation contributed to the initiation of fires in the nuclear bombings in Japan. It is possible that, up to a mile or so from ground zero, some fires may have originated from secondary causes, such as upsetting of stoves, electrical short-circuits, broken gas lines, and so on, which were a direct effect of the blast wave. A number of fires in industrial plants were initiated by furnaces and boilers being overturned, and by the collapse of buildings on them.

7.95 Once the fires had started, there were several factors, directly related to the destruction caused by the nuclear explosion, that influenced their spreading. By breaking windows and blowing in or

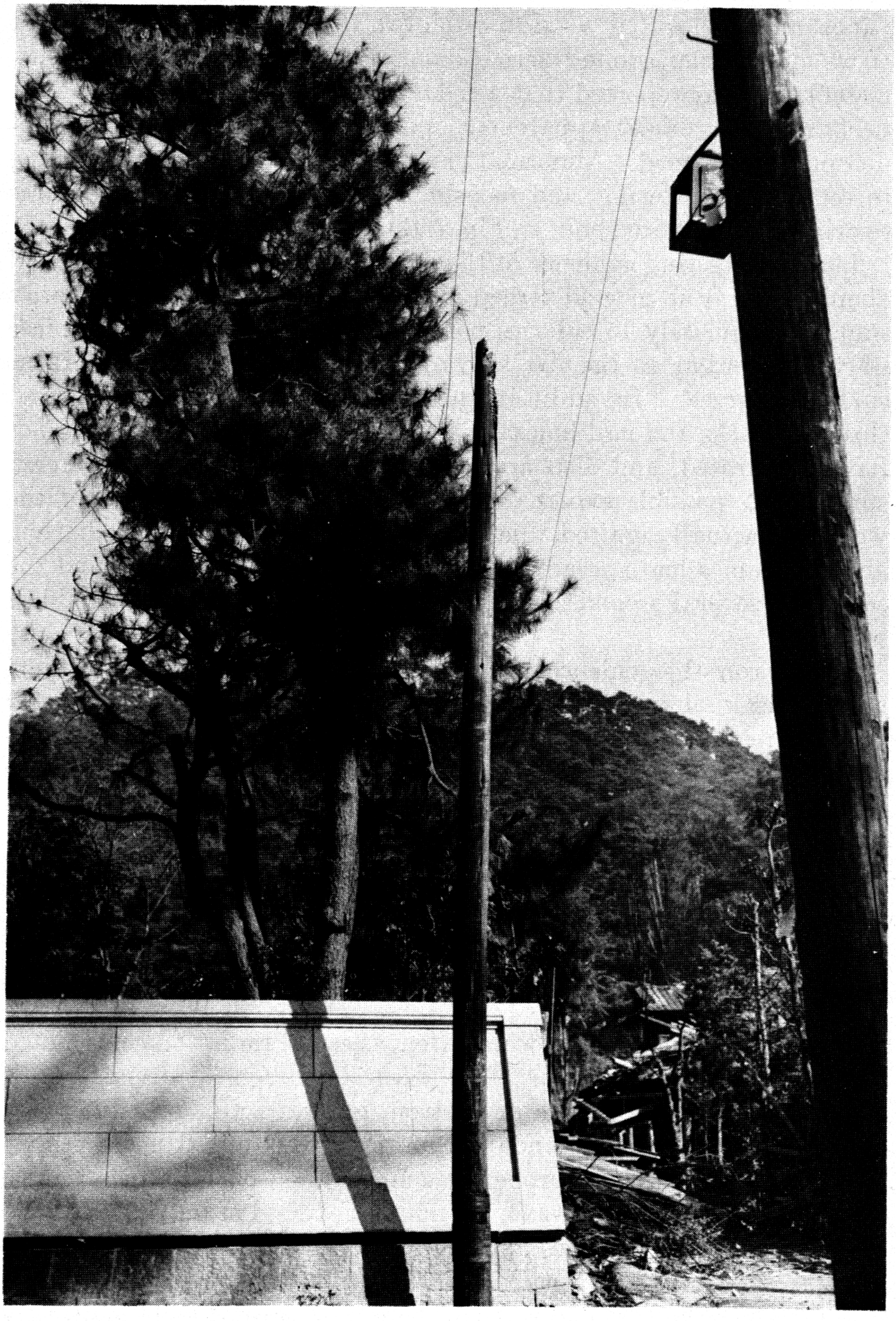

Figure 7.91. The top of a wood pole was reported as being ignited by the thermal radiation (1.25 miles from ground zero at Hiroshima). Note the unburned surroundings; the nearest burned building was 360 feet away.

damaging fire shutters (Fig. 7.95), by stripping wall and roof sheathing, and collapsing walls and roofs, the blast made many buildings more vulnerable to fire. Noncombustible (fire-resistive) structures were often left in a condition favorable to the internal spread of fires by damage at stairways, elevators, and in firewall openings, as well as by the rupture and collapse of floors and partitions (Fig. 4.85d).

Figure 7.95. Fire shutters in building blown in or damaged by the blast; shutter at center probably blown outward by blast passing through building (0.57 mile from ground zero at Hiroshima).

7.96 On the other hand, when combustible frame buildings were blown down, they did not burn as rapidly as they would have done had they remained standing. Further, the noncombustible debris produced by the blast frequently covered and prevented the burning of combustible material. There is some doubt, therefore, whether, on the whole, the effect of the blast was to facilitate or to hinder the development of fires at Hiroshima and Nagasaki.

7.97 Although there were firebreaks, both natural, e. g., rivers and open spaces, and artificial, e. g., roads and cleared areas, in the Japanese cities, they were not very effective in preventing the fires from spreading. The reason was that fires often started simultaneously on both sides of the firebreaks, so that they could not serve their intended purpose. In addition, combustible materials were frequently strewn across the firebreaks and open spaces, such as yards and street areas, by the blast, so that they could not prevent the spread of fires. Nevertheless, there were a few instances where firebreaks assisted in preventing the burn-out of some fire-resistive buildings.

7.98 One of the important aspects of the nuclear bomb attacks on Japan was that, in the large area that suffered simultaneous blast damage, the fire departments were completely overwhelmed. It is true that the fire-fighting services and equipment were poor by American standards, but it is doubtful if much could have been achieved, under the circumstances, by more efficient fire departments. At Hiroshima, for example, 70 percent of the fire-fighting equipment was crushed in the collapse of fire houses, and 80 percent of the personnel were unable to respond. Even if men and machines had survived the blast, many fires would have been inaccessible because of the streets being blocked with debris. For this reason, and also because of the fear of being trapped, a fire company from an area which had escaped destruction was unable to approach closer than 6,600 feet (1.25 miles) from ground zero at Nagasaki. It was almost inevitable, therefore, that all buildings within this range would be destroyed.

7.99 Another contributory factor to the destruction by fire was the failure of the water supply in both Hiroshima and Nagasaki. The pumping stations were not largely affected, but serious damage was sustained by distribution pipes and mains, with a resulting leakage and drop in available water pressure. Most of the lines above ground were broken by collapsing buildings and by heat from the fires which melted the pipes. Some buried water mains were fractured and others were broken due to the collapse or distortion of bridges upon which they were supported (§4.113).

Fire Storm in Hiroshima

7.100 About 20 minutes after the detonation of the nuclear bomb at Hiroshima, there developed the phenomenon known as "fire storm." This consisted of a wind which blew toward the burning area of the city from all directions, reaching a maximum velocity of 30 to 40 miles per hour about 2 to 3 hours after the explosion, decreasing to light or moderate and variable in direction about 6 hours after. The wind was accompanied by intermittent rain, light over the center of the city and heavier about 3,500 to 5,000 feet (0.67 to 0.95 mile) to the north and west. Because of the strong inward draft at ground level, the fire storm was a decisive factor in limiting the spread of the fire beyond the initial ignited area. It accounts for the fact that the radius of the burned-out area was so uniform in Hiroshima and was not much greater than the range in which fires started soon after the explosion. However, virtually everything combustible within this region was destroyed.

7.101 It should be noted that the fire storm is by no means a special characteristic of the nuclear bomb. Similar fire storms have been reported as accompanying large forest fires in the United States, and especially after incendiary bomb attacks in both Germany and Japan during World War II. The high winds are produced largely by the updraft of the heated air over an extensive burning area. They are thus the equivalent, on a very large scale, of the draft of a chimney under which a fire is burning. The rain associated with a fire storm is apparently due to the condensation of moisture on particles from the fire when they reach a cooler area.

7.102 The incidence of fire storms is dependent on the conditions existing at the time of the fire. Thus, there was no such definite storm over Nagasaki, although the velocity of the southwest wind, blowing between the hills, increased to 35 miles an hour when the conflagration had become well established, perhaps about 2 hours after the explosion. This wind tended to carry the fire up the valley in a direction where there was nothing to burn. Some 7 hours later, the wind had shifted to the east and its velocity had dropped to 10 to 15 miles per hour. These winds undoubtedly restricted the spread of fire in the respective directions from which they were blowing. The small number of dwellings exposed in the long narrow valley running through Nagasaki probably did not furnish sufficient fuel for the development of a fire storm as compared to the many buildings on the flat terrain at Hiroshima.

TECHNICAL ASPECTS OF THERMAL RADIATION[6]

Spectral Distribution of Energy from Ball of Fire

7.103 If it can be assumed that the ball of fire in a nuclear explosion, like the sun, behaves rather like a black body, i. e., as a perfect radiator, the distribution of the thermal radiation energy over the

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[6] The remaining sections of this chapter may be omitted without loss of continuity.

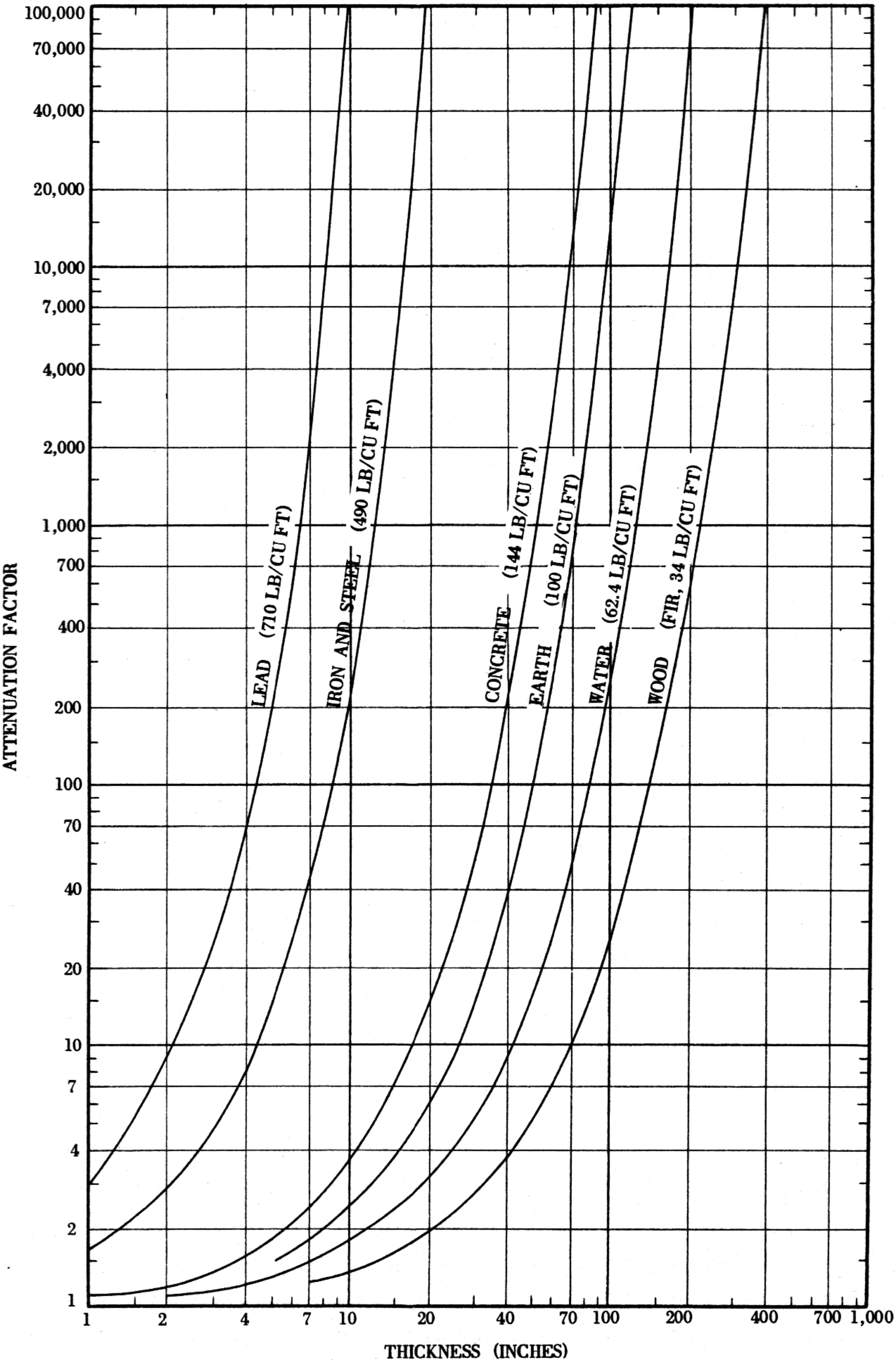
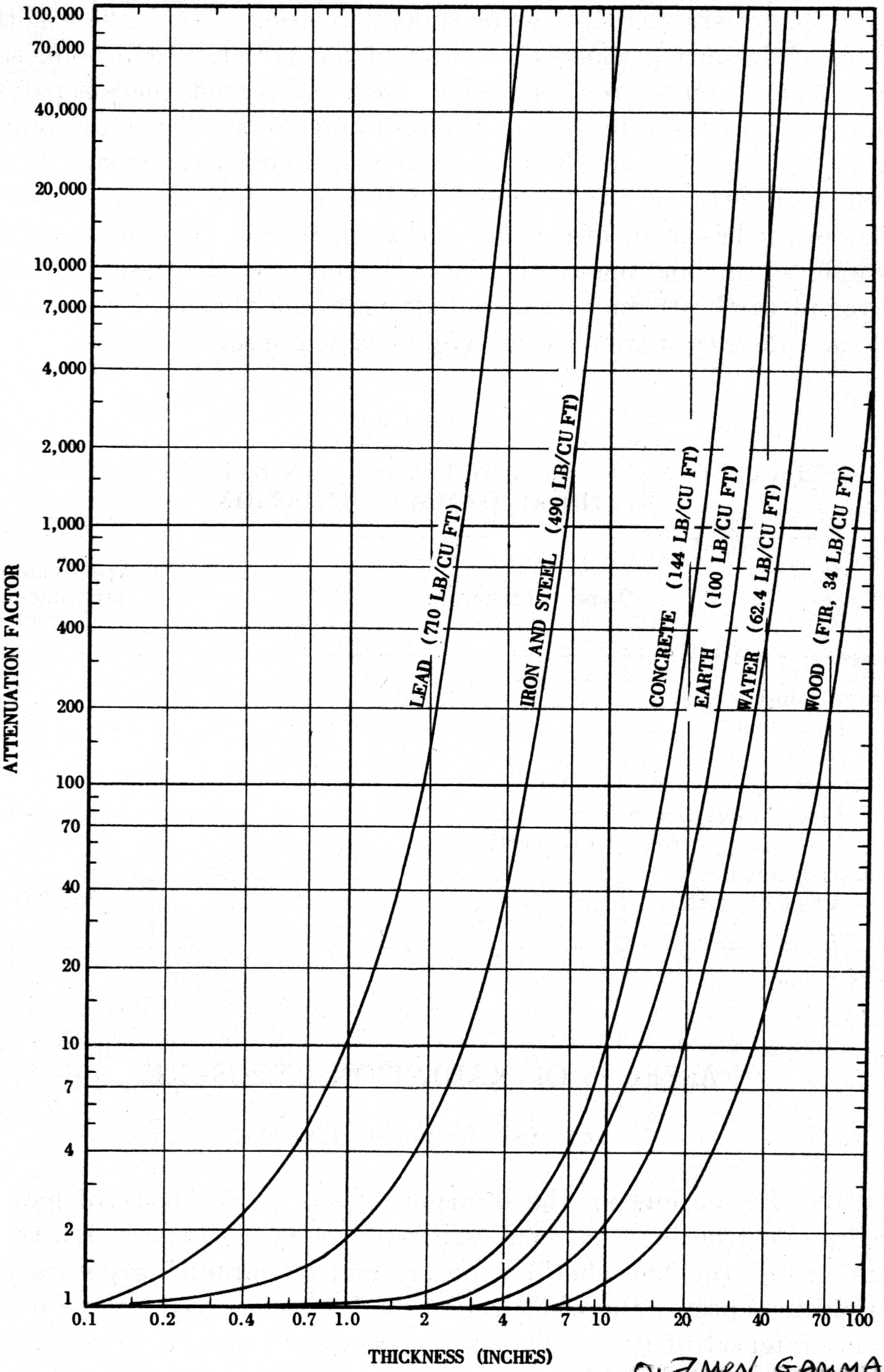


Figure 8.47. Attenuation of initial gamma radiation.



0.7 MeV GAMMAS

Figure 9.36. Attenuation of fission product radiation. (FALLOUT)

CHAPTER XII

PROTECTIVE MEASURES

INTRODUCTION

TYPES OF PROTECTION

12.1 In the preceding chapters of this book the destructive effects of nuclear weapons have been described and discussed. These effects include damage to structures and injury to personnel caused by air blast, ground and water shock, thermal radiations, and initial and residual nuclear radiations. In the present chapter an attempt will be made to state some of the many considerations involved in planning countermeasures against these various effects. The problem of protection is a complex one, since it involves not only the effects themselves, but also economic, social, and psychological considerations, in addition to the methods and efficacy of the systems for providing warning of an impending attack.

12.2 The descriptions of various effects in this book have been given in terms that are reasonably exact. But in planning protection, so many uncertainties are encountered that precise analysis of a particular situation is impossible. Among the more obvious variables are the aiming point for a given target, yield of weapon, height and nature of burst, bombing errors, topography of the target, and weather conditions.

12.3 In general, there are two categories of protection against weapons effects; they may be summed up as "distance" and "shielding." In other words, it is necessary either to get beyond the reach of the effects, or to provide protection against them within their radii of damage. The first principle, that of distance, determines the Civil Defense concept of evacuation of populations from potential target areas.[1] In any discussion of evacuation, this book is of value only as an aid to determining what might constitute a safe distance for evac-

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[1] The evacuation problem is treated in the following publications of the Federal Civil Defense Administration: "Procedure for Evacuation Traffic Movement Studies," TM–27–1; "Evacuation of Civil Populations in Civil Defense Emergencies," TB–27–1; "Evacuation Check List," TB–27–2.

uees, bearing in mind that the effect of fallout enormously complicates the evacuation problem by producing a hazard far beyond the zone of direct damage. Consequently, this chapter will be devoted only to some of the considerations involved in the principle of shielding, which may also be defined as shelter or protective construction.

12.4 The problem of protection by the provision of suitable shielding is itself a very complex one. It is not quite as difficult, however, as the existence of so many factors, as mentioned in § 12.1, might imply. In many cases, proper precautions against blast, shock, and fire damage would also decrease the hazards to personnel from various radiations, both thermal and nuclear.

12.5 As far as burning caused by thermal radiation is concerned, the essential points are protection from direct exposure for human beings, and the avoidance of easily combustible trash and dark-colored materials, especially near windows. The only known defense against gamma rays and neutrons present in the nuclear radiations is the interposition of a sufficient mass of material between the individual and the nuclear bomb, including the rising ball of fire and the subsequent fallout, if any. The use of concrete as a construction material, which is desirable for reducing air-blast and ground-shock damage, will diminish to a great extent the nuclear radiation hazard. The addition of an earth cover will be helpful in this connection.

12.6 From the standpoint of physical damage, the problems of construction to resist the action of blast from nuclear weapons are somewhat different from those associated with bombs of the conventional type. A TNT bomb will generally blow a building into pieces, but a nuclear weapon causes failure by collapsing or pushing over the structure as a whole. The relatively long duration of the blast wave from the large energy release of a nuclear explosion, as compared with that from an ordinary explosion, results in a significant difference in the nature of the effects (see Chapter III).

12.7 Another important difference between the consequences of nuclear and conventional explosions is the great increase in the area damaged in the former case. Even bombs of 20-kiloton energy yield, such as were exploded over Japan, can cause devastation over an area of several square miles (Fig. 12.7). With weapons in the megaton range, the damaged region may cover a hundred or more square miles.

GENERAL CONSIDERATION OF PROTECTIVE MEASURES

12.8 The most effective, but not necessarily most practical, method of minimizing the danger from nuclear weapons would be by dispersal

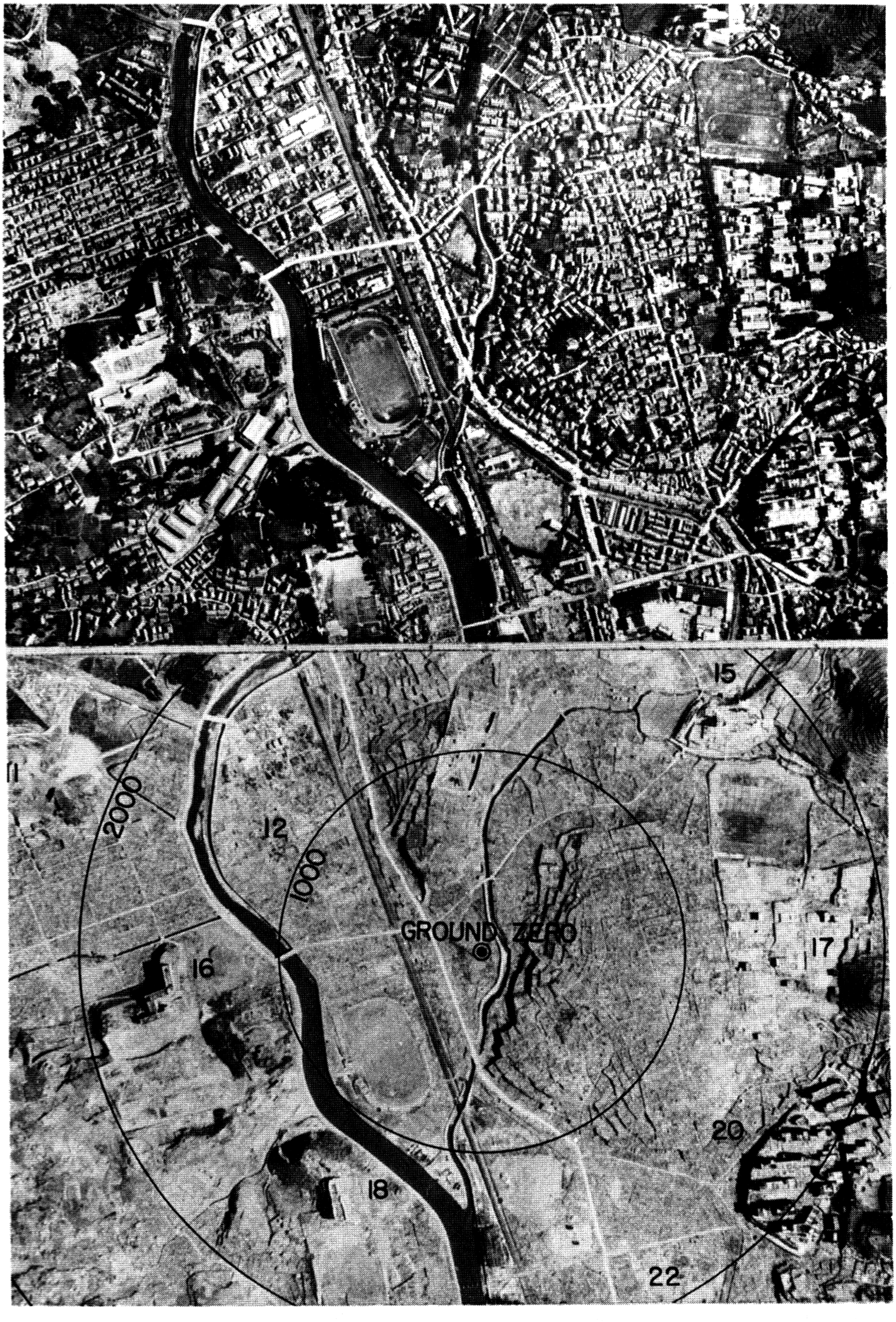

Figure 12.7. Area around ground zero at Nagasaki before and after the atomic explosion (1,000-foot radius circles are shown).

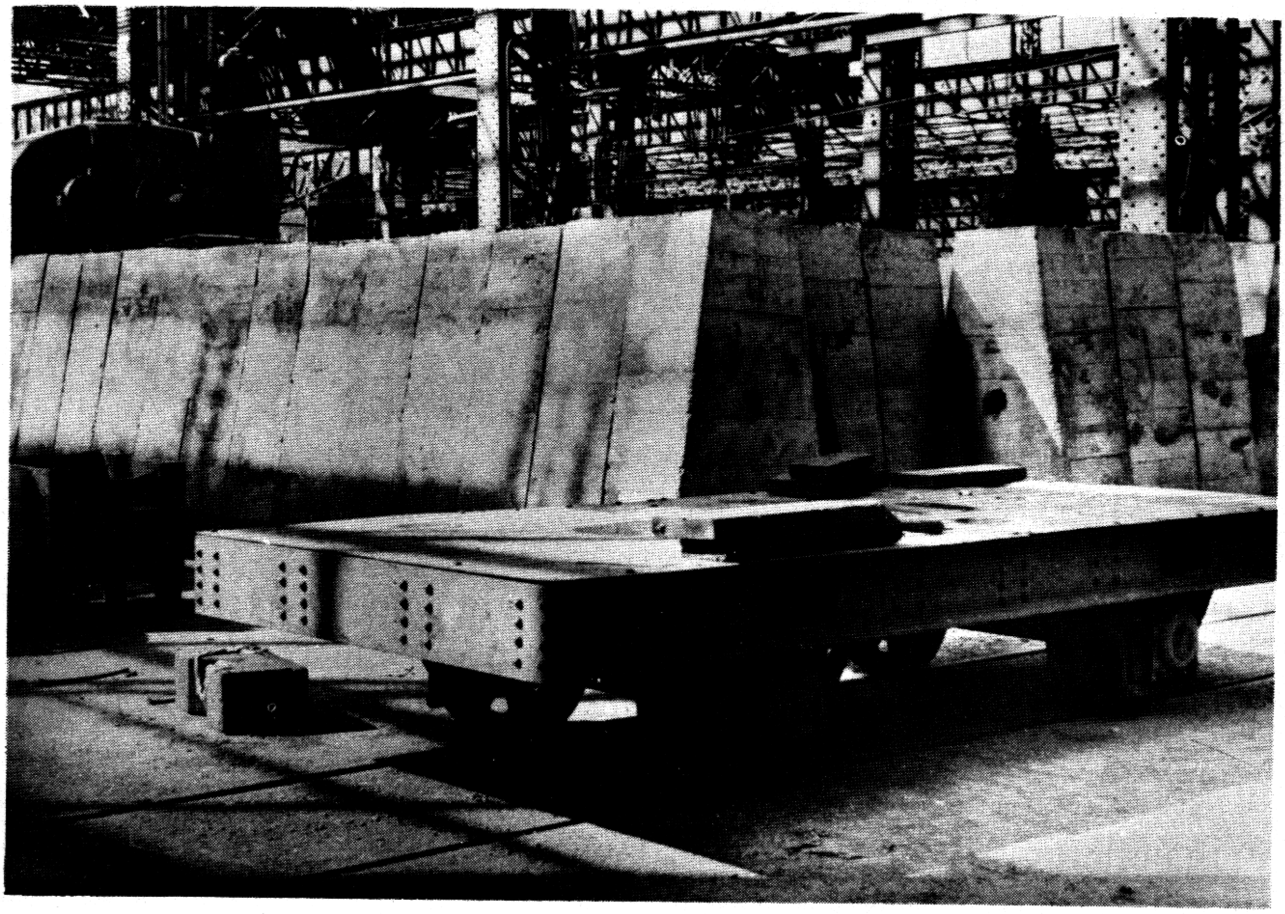

Figure 12.37a. Precast, reinforced-concrete blast walls (0.85 mile from ground zero at Nagasaki).

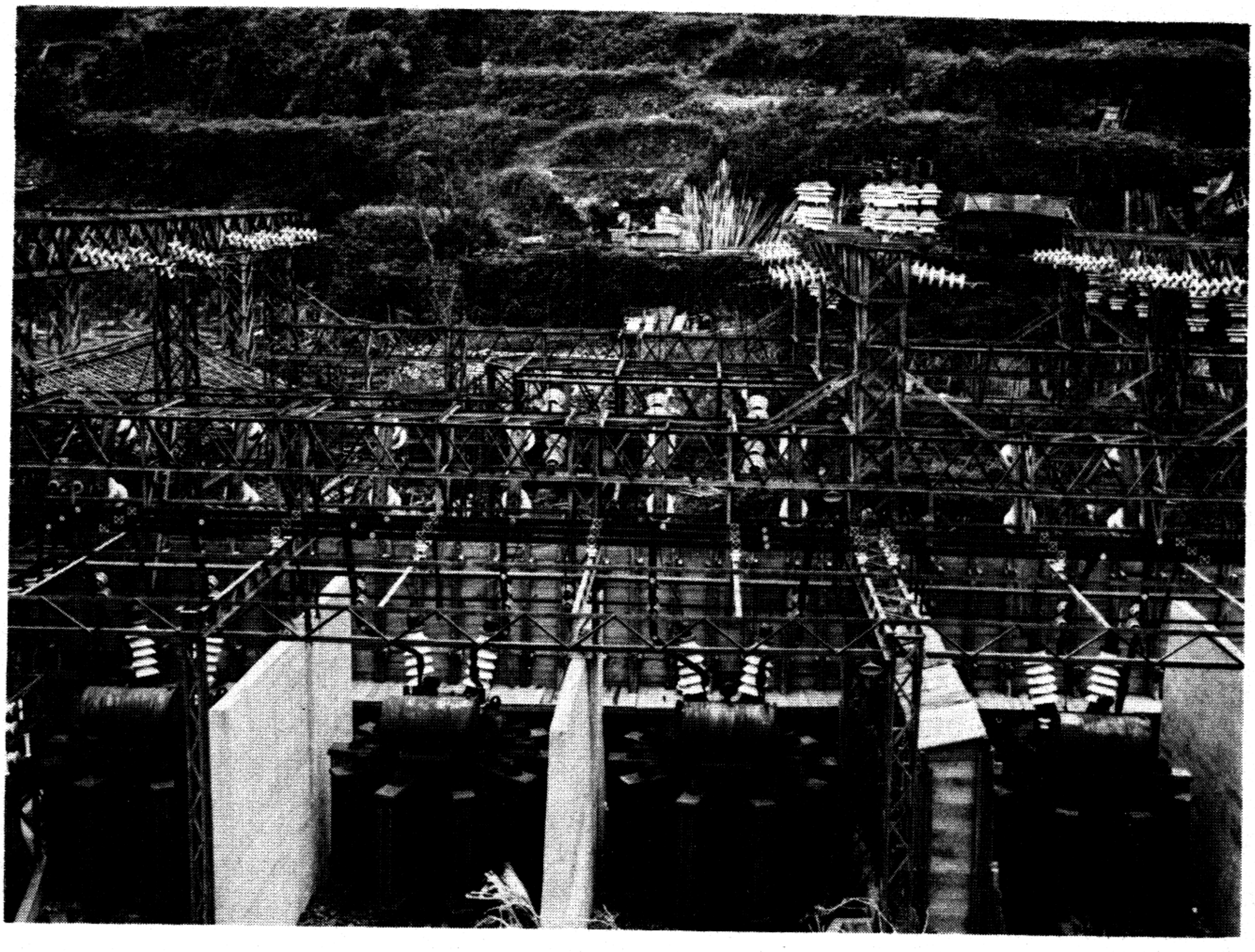

Figure 12.37b. Reinforced-concrete blast walls protecting transformers (1 mile from ground zero at Nagasaki).

Figure 12.37c. **Earth-filled, wooden blast walls protecting machinery (0.85 mile from ground zero at Nagasaki).**

PROTECTION BY TRENCHES AND EARTH REVETMENTS

12.38 Although they are not strictly structures, in the sense used above, attention should be called to the significant protection that can be afforded by trenches and earth revetments, especially to drag-sensitive targets. A shallow pit provides little shielding, but pits or trenches that are deeper than the target have been found to be very effective in reducing the magnitude of the drag forces impinging on any part of the target. In these circumstances, the lateral loading is greatly reduced and the damage caused is restricted mainly to that due to the crushing action of the blast wave.

12.39 The only types of shielding against drag forces which have been found to be satisfactory so far are those provided by fairly extensive earth mounds (or revetments) and deep trenches, since these are themselves relatively invulnerable to blast. Such protective trenches are not recommended for use in cities, however, because of the damage that would result from debris falling into them. Although sandbag mounds have proved satisfactory for protection against conventional high explosives and projectiles, they are inadequate against nuclear blast because they may become damaging missiles.

Figure 12.40a. Earth-moving equipment subjected to nuclear blast in open terrain (30 psi overpressure).

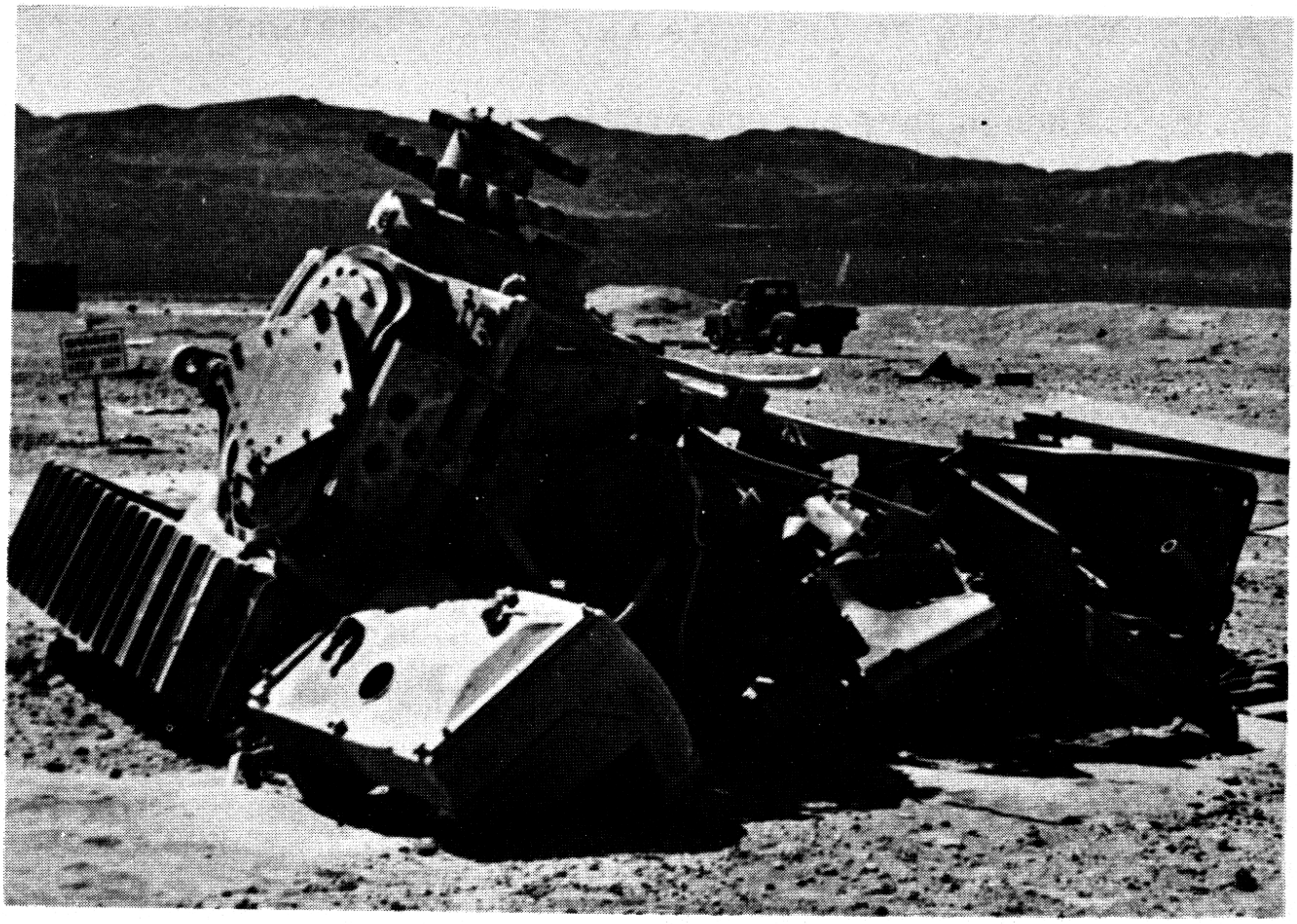

Figure 12.40b. Earth-moving equipment subjected to nuclear blast in open terrain (30 psi overpressure).

Figure 12.40c. Earth-moving equipment protected in deep trench at right angles to blast wave motion (30 psi overpressure).

12.40 The destruction caused by a nuclear explosion to two pieces of earth-moving equipment, which are largely drag-sensitive, is shown in Figs. 12.40a and b. Two similar pieces of equipment located in a deep trench, at the same distance from the explosion, are seen in Fig. 12.40c to have been essentially unharmed. It is important to mention that the main direction of the trench was at right angles to the motion of the blast wave. If the wave had been traveling in the same direction as the trench, the equipment would probably have been severely damaged. Consequently, in order to provide protection from drag forces, the orientation of the trench or earth revetment, with respect to the expected direction of the explosion, is of great importance.

FIRE PROTECTION

12.41 It was noted in Chapter VII that fires following a nuclear explosion may be started by thermal radiation and by secondary effects, such as overturning stoves and furnaces, rupture of gas pipes, and electrical short circuits. Fire-resistive construction and avoidance of fabrics and other light materials of inflammable character are essential in reducing fire damage. As shown by the tests described in § 7.82, a well-maintained house, with a yard free from inflammable rubbish, was less easily ignited by thermal radiation than a house that has not had adequate care.

12.42 The methods of fire-resistive design and of city planning are well known and the subject need not be treated here. A special requirement is the reduction of the chances of ignition due to thermal radiation by the avoidance of trash piles and other finely divided fuel as well as combustible, especially dark colored, materials that might be exposed at windows or other openings. It has been recommended, in this connection, that all such openings be shielded against thermal radiation from all directions. The simple device of whitewashing windows will greatly reduce the transmission of thermal radiation and so decrease the probability of fires starting in the interior of the building. Other practical possibilities are the use of metal venetian blinds, reflective coatings on the window glass, and nonflammable interior pull curtains.

12.43 To judge from the experience in Japan, where the distortion by heat of exposed structural frames was considerable, it would appear desirable that steel columns and other steel members be protected from fire, especially where the contents of the building are flammable or where the building is located adjacent to flammable structures. Further, narrow firebreaks in Japan were found to be of little value. It is vital, therefore, that such firebreaks as may be provided in city planning or by demolition must be adequate for a major conflagration. A minimum width of 100 feet has been suggested.

12.44 One of the most important lessons learned from the nuclear bomb attacks on Japan is the necessity for the provision of an adequate water supply for the control of fires. In Nagasaki, the water pressure was 30 pounds per square inch at the time of the explosion, but chiefly because of numerous breaks in house service lines it soon dropped to 10 pounds per square inch. On the day following the explosion the water pressure was almost zero. This drop in the pressure contributed greatly to the extensive damage caused by fire. The experience in Hiroshima was quite similar.

SHELTERS FOR PERSONNEL

Introduction

12.45 Ideally, a shelter for personnel might be required to provide protection against air blast, ground shock, thermal radiation, initial nuclear radiation (neutrons and gamma rays), and residual nuclear radiation from fallout (external and internal sources). Such an ideal shelter is, however, virtually impossible to attain, in view of the uncertainties mentioned in § 12.2. Thus, shelter design, like that of

12.60 In the event of a surprise attack, when there is no opportunity to take shelter, immediate action could mean the difference between life and death. The first indication of an unexpected nuclear explosion would be a sudden increase of the general illumination. It would then be imperative to avoid the instinctive tendency to look at the source of light, but rather to do everything possible to cover all exposed parts of the body. A person inside a building should immediately fall prone and crawl behind or beneath a table or desk. This will provide a partial shield against splintered glass and other flying missiles. No attempt should be made to get up until the blast wave has passed, as indicated possibly by the breaking of glass, cracking of plaster, and other signs of destruction. The sound of the explosion also signifies the arrival of the blast wave.

12.61 A person caught in the open by the sudden brightness due to a nuclear explosion, should drop to the ground while curling up to shade the bare arms, hands, neck, and face with the clothed body. Although this action may have little effect against gamma rays and neutrons, it might possibly help in reducing flash burns due to thermal radiation. The degree of protection provided will vary with the energy yield of the explosion. As stated in § 7.53, it is only with high-yield weapons that evasive action against thermal radiation is likely to be feasible. Nevertheless, there is nothing to be lost, and perhaps much to be gained, by taking such action. The curled-up position should be held until the blast wave has passed.

12.62 If shelter of some kind, no matter how minor, e. g., in a doorway, behind a tree, or in a ditch, or trench can be reached within a second, it might be possible to avoid a significant part of the initial nuclear radiation, as well as the thermal radiation. But shielding from nuclear radiation requires a considerable thickness of material and this may not be available in the open. By dropping to the ground, some advantage may be secured from the shielding provided by the terrain and surrounding objects. However, since the nuclear radiation continues to reach the earth from the atomic cloud as it rises, the protection will be only partial. Further, as a result of scattering, the radiations will come from all directions.

PROTECTION FROM FALLOUT

Passive and Active Measures

12.63 Protection against the residual nuclear radiation from fallout presents a number of difficult and involved problems. This is so

12.82 Decontamination may be either gross, i. e., rough, or detailed. Gross decontamination is the rapid, partial removal or covering of contamination on a large scale. Its purpose is to reduce the radiation dose rate as quickly as possible to a point where personnel can use a piece of equipment or remain within an area for a limited period of time, at least. Subsequently, detailed decontamination, which is a lengthy and thorough process, may be carried out. As a general rule, decontamination cannot (and need not) be complete. However, the procedure should be carried to the point where the situation no longer constitutes a significant hazard under the particular conditions of use or occupation.

12.83 The decision to undertake decontamination will depend upon the circumstances, and must involve a calculated risk. Since there is always a certain degree of danger to the operating personnel, the procedure should be deferred as long as is reasonably possible, so as to take advantage of natural radioactive decay. In some cases urgent action may be necessary, and decontamination may have to be started while the radiation level is still high. Such a situation might be met by replacement of the workers with fresh, previously unexposed, crews at short intervals.

12.84 There are a few useful general principles relating to contamination and decontamination which should be borne in mind. Because of its particulate nature, the fallout will obviously tend to collect on horizontal surfaces. Such surfaces will thus be more highly contaminated than vertical surfaces. Hence, in preliminary decontamination, at least, the latter can be ignored. Most of the fallout particles can be readily removed either by washing with a stream of water or by sweeping, preferably with a vacuum cleaner to avoid inhalation of dust.

12.85 Gross decontamination can generally be performed in one or other of these ways. For smooth, e. g., painted and metallic, surfaces, wet (washing) methods may be used, but for porous materials, e. g., fabrics, brick, concrete, and stone, dry methods are to be preferred. Broadly speaking, water washing can be employed outdoors and on the exterior of vehicles, whereas vacuum sweeping is more suitable for the interiors of buildings and vehicles. Experimental tests of decontamination procedures have shown that the major portions of contaminating material can be removed by these simple methods. Only a small part of the contamination is strongly held and requires more drastic treatment, e. g., with chemicals or abrasives.[5]

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[5] Contamination due to neutron-induced activity is difficult to remove, but such contamination is of importance only near the explosion center (see § 9.18).

12.86 In a city, decontamination could be carried out by hosing the roofs of buildings and the streets with strong streams of water. The radioactive material would thus be transferred to the storm sewers, where it would represent only a minor hazard. As an alternative to hosing, the dose rate inside a building could also be reduced by covering the ground surrounding the building with uncontaminated earth or by removing the top layer of the ground to a distance with a bulldozer.

12.87 It is important to note, in connection with removal of contaminated earth, for the purpose just described or to provide a means of transit, that the gamma rays from fission products can travel considerable distances through air. For example, at 3 feet above the ground, roughly 50 percent of the dose rate received in the center of a large, flat, uniformly contaminated area comes from distances greater than 25 feet away, and about 25 percent from distances more than 50 feet away. Thus, complete removal of the contaminated surface from a circle 50 feet in radius would reduce the dose rate in the center to about one-fourth of its original value. However, if the contaminated earth were not completely removed, but just pushed to the outside of the circle, the dose rate would be considerably larger than one-fourth the initial value.

12.88 It is apparent, therefore, that if transit facilities are to be provided across open country which is contaminated over a large area, bulldozing the top few inches of contaminated soil to the sides will be satisfactory only if a wide strip is cleared. Thus, if the strip is 250 feet in width, the radiation dose rate in the middle will be reduced to one-tenth of the value before clearing. A similar result may be achieved by scraping off the top layer of soil and burying it under fresh soil. Something like a foot of earth would be required to decrease the dose rate by a factor of ten.

12.89 Badly contaminated clothing, as well as rugs, curtains, and upholstered furniture, would have to be discarded and buried or stored in an isolated location. When the radioactivity has decayed to a sufficient extent, or if the initial contamination is not too serious, laundering may be effective in reducing the activity of clothing and fabrics, to permit their recovery. Thorough vacuum cleaning of furniture might be adequate in some cases, but an instrument check would be necessary before further use.

PROTECTION OF OPERATING CREWS

12.90 All personnel entering a contaminated area, to perform survey monitoring, decontamination, or other emergency operations, should adapt their clothing to prevent the entry of dust. The main purpose of this precaution is to minimize the possibility of "beta burns" as a result of direct contact of the fallout with the skin (see § 11.94). It should be remembered, of course, that clothing offers virtually no protection against gamma radiation, and so this hazard will still exist to an undiminished extent.

12.91 For dry operations, heavy pants and shoes are recommended, as well as cotton or canvas work gloves and a tight-fitting cap. In dusty areas it is advisable that the bottoms of the pants and the ends of the sleeves (over the gloves) be tied to prevent the entry of contaminated material. A scarf around the neck would also help in this connection. After a nuclear attack, the dust may arise from rubble, disturbance of the ground, etc., and may not necessarily be radioactive. Precautions to reduce inhalation of the dust in large amounts would be desirable, in any event. Consequently, in operations in which considerable quantities of dust may be encountered, goggles and a filter mask are advisable.

12.92 For wet decontamination operations, water-repellent clothing, rubber boots, and rubber gloves will be required (Fig. 12.92). They can be cleaned with a stream of water and used several times, provided there are no breaks or tears.

12.93 In addition to taking steps to prevent radioactive material from reaching the skin, workers will need protection from excessive exposure to radiation. For this purpose, each operator should carry a self-indicating meter, sometimes called an "organizational dosimeter," to record his total radiation exposure. Various types of dosimeters have been devised, and simple and reliable instruments, that can be produced cheaply and in large numbers, are available.[6]

12.94 Survey meters for the determination of radiation intensities (dose rates) will be required in order to detect regions of high activity and for estimating permissible times of stay in a contaminated area. As a general rule, instruments which measure the dose rate of gamma radiation will be satisfactory. In addition, special instruments sensitive to beta radiations are advantageous for such purposes as detecting beta-particle emitters on the body.

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[6] For a description of dosimeters and other radiation instruments developed by the Federal Civil Defense Administration, see "Radiological Instruments for Civil Defense," TB–11–20.

Figure 12.92 Water-repellent clothing for use in wet decontamination operations.

12.95 In connection with this aspect of personnel protection, there arises the question of the amount of nuclear radiation exposure that is permissible for those taking part in emergency operations. It is difficult, if not impossible, to supply an exact answer, for a great deal will depend upon the circumstances and the risks that must inevitably be taken.

12.96 In those phases of emergencies in which immediate action is required, it would rarely be possible to predict in advance the radiation dose that might be received as a result of such action. The consequences to the exposed individuals, would, therefore, be equally unpredictable. However, where the hazard could be estimated from available dose rate data, it might be possible to establish an approximate guide concerning permissible radiation exposures under emergency conditions.[7]

FOOD AND WATER

12.97 Foods that are properly covered or wrapped or are stored in closed containers should suffer little or no contamination. This will be true for canned and bottled foods as well as for any articles in impervious, dust-proof wrappings. If the contamination is only on the outside, all that would be necessary for recovery purposes would be the careful removal, e. g., by washing, of any fallout particles that might have settled on the exterior of the container.[8] Even vegetables could be satisfactorily decontaminated by washing. If this were followed by removal of the outer layers, by peeling, the food should be perfectly safe for human consumption. Unprotected food products of an absorbent variety that have become contaminated should be disposed of by burial.

12.98 As for food crops grown in contaminated soil, there is not yet sufficient information available. Some radioactive isotopes may be taken up by the plant, but their nature and quantity will vary from one species to another and also, probably, with the soil characteristics (§ 9.99). All that can be stated at the present time is that plants grown in contaminated soil should be regarded with suspicion until their safety can be confirmed by means of radiological instruments.

12.99 Most sources of public water supplies are located at a considerable distance from urban centers that might be targets of a nuclear attack. Nevertheless, appreciable contamination might result if the watershed were in the range of heavy fallout from a surface burst. Other possibilities are fallout particles dropping into a river or reservoir or the explosion of a nuclear bomb near a reservoir. In most cases it is to be expected that, as a result of the operation of several factors, e. g., dilution by flow, natural decay, and removal ("adsorption") by soil, the water will be fit for consumption, on an emergency basis, at least, except perhaps for a limited time immediately following the nuclear explosion. In any event, where the water from a reservoir is subjected to regular treatment, including coagu-

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[7] See, for example, "Emergency Exposures to Nuclear Radiation," Federal Civil Defense Administration Technical Bulletin (TB–18–1).

[8] Food could become contaminated even inside containers due to neutron-induced activity, but this is not likely to be important in locations where the packaged foodstuffs have survived the nuclear explosion intact (§ 9.25).

lation, sedimentation, and filtration, it is probable that much of the radioactive material would be removed.

12.100 Because soil has the ability to take up and retain certain elements by the process of "adsorption," underground sources of water will generally be free from contamination. For the same reason, moderately deep wells, even under contaminated ground, can be used as safe sources of drinking water, provided, as is almost invariably the case, there is no direct drainage from the surface into the well.

12.101 In some cities, water is taken directly from a river and merely chlorinated before being supplied for domestic purposes. The water may be unfit for consumption for several days, but, as a result of dilution and natural decay, the degree of contamination will decrease with time. It would be necessary, in cases of this kind, to subject the water to examination for radioactivity and to withhold the supply until it is reasonably safe. Assuming the contamination is due to fission products, the acceptable total beta (or gamma) activities under emergency conditions, for 10 and 30 day periods, respectively, are given in Table 12.101. Thus, if it is anticipated that the water will have to be used regularly for a period of 30 days, the maximum permissible activity is 3×10^{-2} microcuries per cubic centimeter (see § 9.125, *et seq.*). On the other hand, if it appears that the period will be shorter, water of proportionately higher activity may be consumed in an emergency.

TABLE 12.101

ACCEPTABLE EMERGENCY BETA (OR GAMMA) ACTIVITIES IN DRINKING WATER

	Activity	
Consumption period (days)	*Microcuries per cubic centimeter*	*Disintegrations per second per cubic centimeter*
10	9×10^{-2}	3×10^{3}
30	3×10^{-2}	1×10^{3}

12.102 The emergency limits for alpha particle emitters, such as uranium and plutonium, in water are appreciably less than those given in Table 12.101. However, it is expected that only in rare circumstances would these elements represent a contamination hazard in drinking water.

12.103 If the regular water supply is not usually subjected to any treatment other than chlorination, and an alternative source is not available, consideration should be given to the provision of ion-exchange columns (or beds) for emergency use in case of contamination.

Home water softeners might serve the same purpose on a small scale. Incidentally, the water contained in a domestic hot-water heater could serve as an emergency supply, provided it can be removed without admitting contaminated water.

12.104 In hospitals and on ships, sufficient water for emergency purposes could be obtained by distillation. It was found after the nuclear tests at Bikini in 1946, for example, that contaminated sea water when distilled was perfectly safe for drinking purposes; the radioactive material remained behind in the residual scale and brine. It should be emphasized, however, that mere boiling of water contaminated with fallout is of absolutely no value as regards removal of the radioactivity.

RADIATION DOSES AND TIMES IN CONTAMINATED AREAS

12.105 For the planning of defensive action, either active or passive, or of survey operations in an area contaminated with fission products, it is necessary either to make some estimate of the permissible time of stay for a prescribed dose or to determine the dose that would be received in a certain time period. The basic equations and the related graphs (Figs. 9.8 and 9.12) were given in Chapter IX, but the same results may be expressed in an alternative form that is more convenient for many purposes.[9]

12.106 If the radiation dose rate from fission products is known at a certain time in a given location, Fig. 12.106 may be used to determine the dose rate at any other time at the same location, assuming there has been no change in the fallout other than natural radioactive decay. The same nomogram can be utilized, alternatively, to determine the time after the explosion at which the dose rate will have attained a specified value. If there has been any change in the situation, either by further contamination or by decontamination, in the period between the two times concerned, the results obtained from Fig. 12.106 will not be valid.

12.107 To determine the total radiation dose received during a specified time of stay in a contaminated area, if the dose rate in that area at any given time is known, use is made of Fig. 12.107, in conjunction with Fig. 12.106. The chart may also be employed to evaluate the time when a particular operation may be commenced in order not to exceed a certain total radiation dose.

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[9] Devices of the slide-rule type, referred to in the footnote to § 9.11, are very useful for making rapid calculations of the kind described here.

12.198 Another type of calculation of radiation dose in a contaminated area is based on a knowledge of the dose rate at the time of entry into that area. The procedure described in the examples facing Fig. 12.107, which also require the use of Fig. 12.106, may then be applied to determine either the total dose received in a specified time of stay or the time required to accumulate a given dose of radiation. The calculation may, however, be simplified by means of Fig. 12.108, which avoids the necessity for evaluating the 1-hour reference dose rate, provided the dose rate at the time of entry into the contaminated area is known.

12.109 If the whole of the fallout reached a given area within a short time, Fig. 12.108 could be used to determine how the total radiation dose received by inhabitants of that area would increase with time, assuming no protection. For example, suppose the fallout arrived at 6 hours after the explosion and the dose rate at that time was *R* roentgens per hour; the total dose received would be 8*R* roentgens in 1 day, 11*R* roentgens in 2 days, and 13*R* roentgens in 5 days.

12.110. It is evident that the first day or so after the explosion is the most hazardous as far as the exposure to residual nuclear radiation from fallout is concerned. Although the particular values given above apply to the case specified, i. e., complete fallout arrival 6 hours after the explosion, the general conclusions to be drawn are true in all cases. The radiation doses that would be received during the first day or two are considerably greater than on subsequent days. Consequently, it is in the early stages following the explosion that protection from fallout is most important.

Fireball of the world's first thermonuclear explosion, Eniwetok Proving Grounds, November 1, 1952 (local time).

The Effects of

Nuclear Weapons

Samuel Glasstone

Editor

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Foreword

This book is a revision of "The Effects of Nuclear Weapons" which was issued in 1957. It was prepared by the Defense Atomic Support Agency of the Department of Defense in coordination with other cognizant governmental agencies and was published by the U.S. Atomic Energy Commission. Although the complex nature of nuclear weapons effects does not always allow exact evaluation, the conclusions reached herein represent the combined judgment of a number of the most competent scientists working on the problem.

There is a need for widespread public understanding of the best information available on the effects of nuclear weapons. The purpose of this book is to present as accurately as possible, within the limits of national security, a comprehensive summary of this information.

Robert S. McNamara

Secretary of Defense

Glenn T. Seaborg

Chairman
Atomic Energy Commission

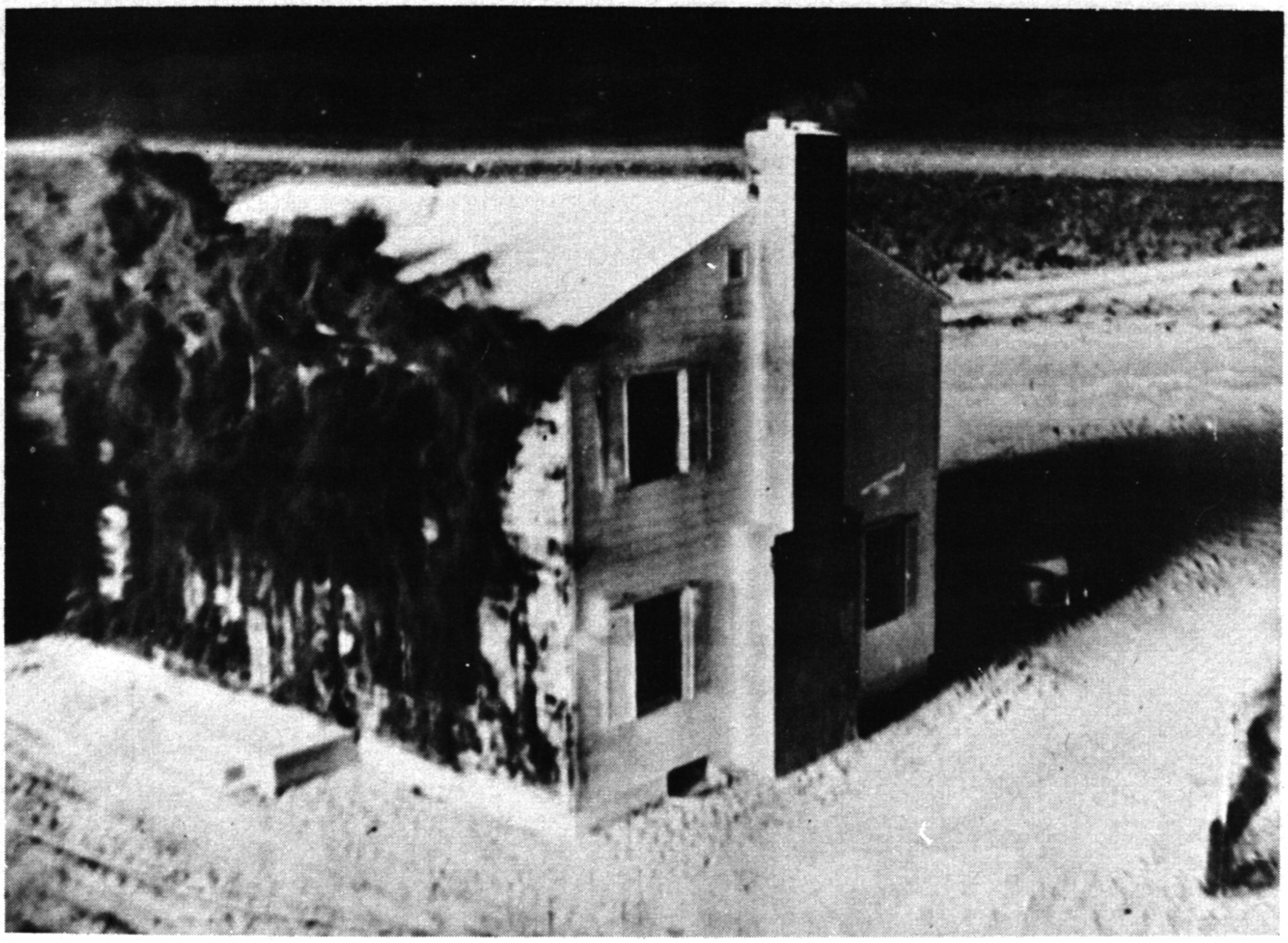

Figure 7.33a. Thermal effects on wood-frame house 1 second after explosion (about 25 cal/sq cm).

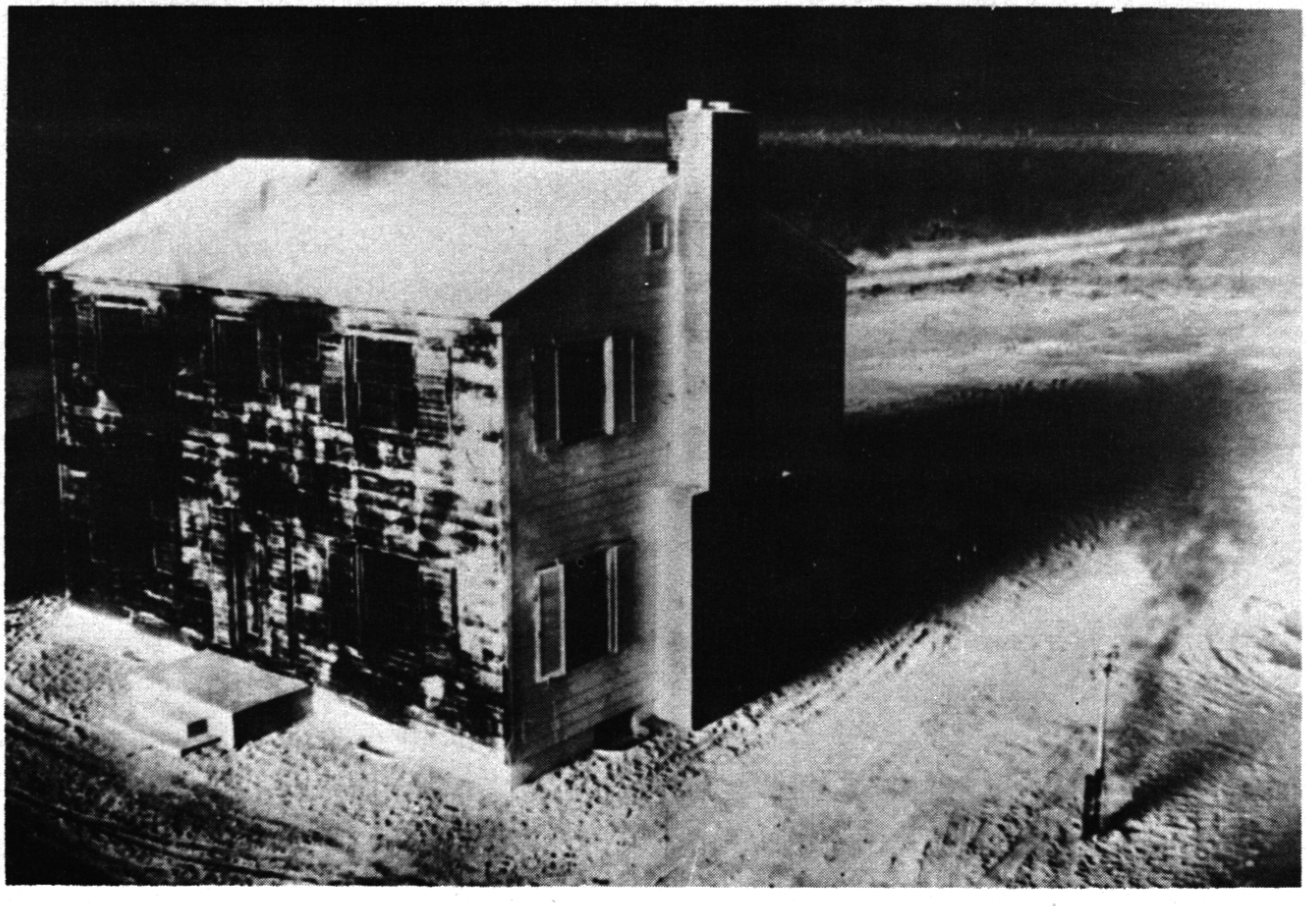

Figure 7.33b. Thermal effects on wood-frame house about ¾ second later.

INCENDIARY EFFECTS

ORIGIN OF FIRES

7.54 There are two general ways in which fires can originate in a nuclear explosion. First, by the ignition of paper, trash, window curtains, awnings, excelsior, dry grass, and leaves, as a direct result of the absorption of thermal radiation. And second, as an indirect effect of the destruction caused by the blast wave, fires can be started by upset stoves and furnaces, electrical short-circuits, and broken gas lines. No matter how the fire originates, its subsequent spread will be determined by the amount and distribution of combustible materials in the vicinity. The manner whereby fires in cities grow and spread from ignition points is a complex matter which will be discussed later. In the meantime, two aspects of the problem of the development of fires accompanying a nuclear explosion will be considered, namely, (1) the number of points at which fires originate, and (2) the character of the surrounding area.

7.55 The initiation of secondary (or indirect) fires is difficult to analyze, but there are some aspects of direct ignition by thermal radiation which are reasonably clear. The most important appears to be what has been called the "density of ignition points." This is the number of points in a given area, e.g., an acre, where exterior combustible materials are present which will produce a primary ignition and may result in a fire. In general, these materials may be expected to ignite when exposed to at least the appropriate radiant energy values given in Tables 7.40 and 7.44. The data in Fig. 7.55 are based on surveys made in a number of large cities in the United States. It is seen that the density of ignition points is greatest in wholesale distribution and slum residential areas, and is least in good residential and large manufacturing areas.[4] Paper was the commonest ignitable material found everywhere except in downtown retail areas where awnings represented the major source of fire.

7.56 The density of ignition points provides some indication of the chance of fires being started under ideal weather conditions. But the results in Fig. 7.55 are by themselves not sufficient to permit an estimate to be made of the number of significant fires that will actually result. In the first place, at locations closer to ground zero where moderate to severe blast damage occurs, almost all ignitable materials will constitute a fire hazard. On the other hand, at greater distances, only those most easily ignitable will catch fire. Further,

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[4] The area types are in accordance with the classification used by the U.S. Bureau of Census.

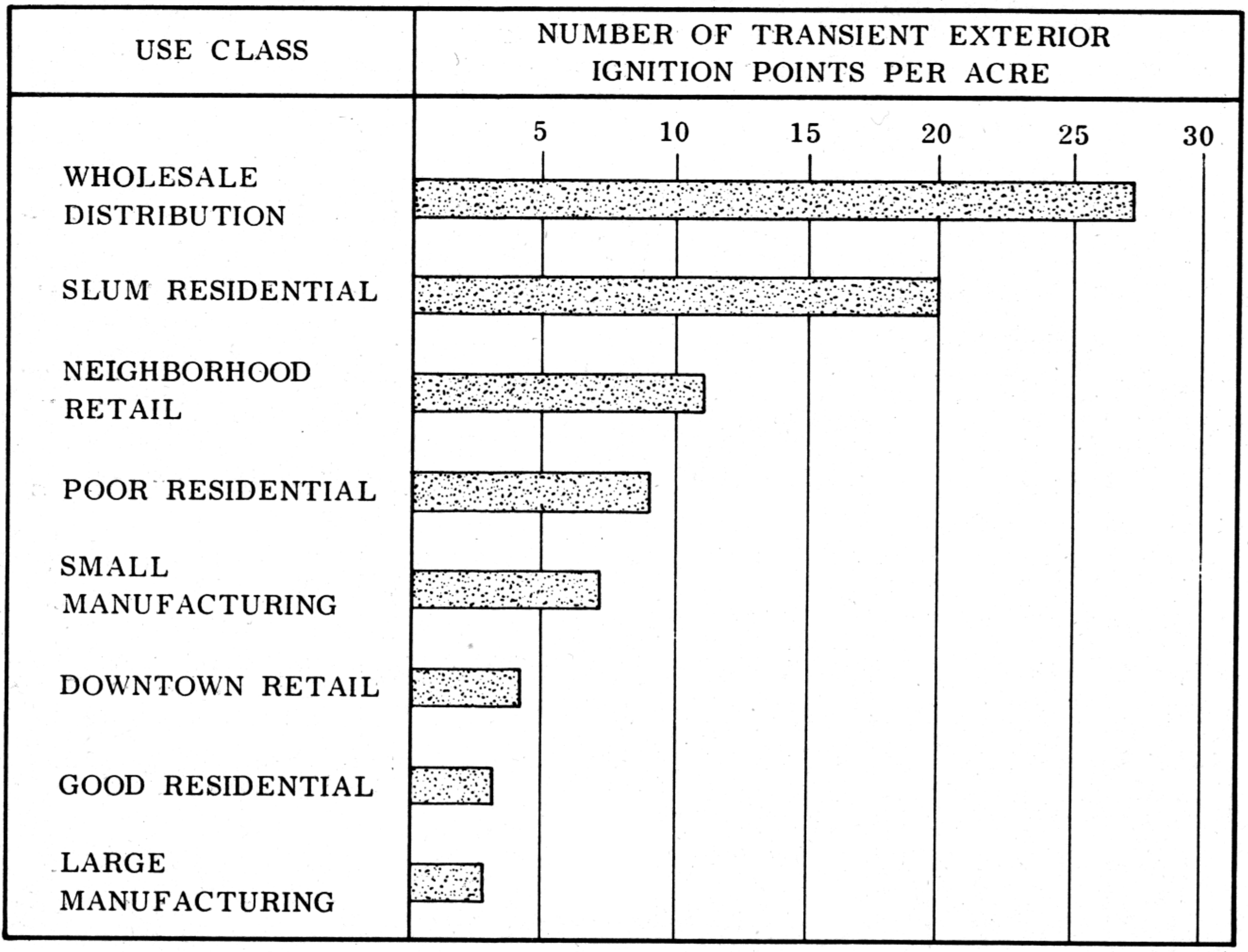

Figure 7.55. Frequency of exterior ignition points for various areas in a city

the formation of a significant fire, capable of spreading, will require appreciable quantities of combustible material close by, and this may not always be available.

7.57 The fact that accumulations of ignitable trash close to a wooden structure represent a real fire hazard was demonstrated at the nuclear tests carried out in Nevada in 1953. In these tests, three miniature wooden houses, each having a yard enclosed with a wooden fence, were exposed to 12 calories per square centimeter of thermal radiation. One house, at the left of Fig. 7.57, had weathered siding showing considerable decay, but the yard was free from trash. The next house also had a clean yard and in addition, the exterior siding was well maintained and painted. In the third house, at the right of the photograph, the siding, which was poorly maintained, was weathered, and the yard was littered with trash.

7.58 The state of the three houses after the explosion is seen in Fig. 7.58. The third house, at the right, soon burst into flame and was burned to the ground. The first house, on the left, did ignite but it did not burst into flame for 15 minutes. The well maintained house in the center with the clean yard suffered scorching only. It is of interest to recall that the wood of a newly erected white-painted

Figure 7.57. Wooden test houses before exposure to a nuclear explosion, Nevada Test Site.

Figure 7.58. Wooden test houses after exposure to a nuclear explosion.

house exposed to about 25 calories per square centimeter was badly charred but did not ignite (see Fig. 7.33b).

7.59 The value of fire-resistive furnishing in decreasing the number of ignition points was also demonstrated in the tests. Two identical, sturdily constructed houses, each having a window 4 feet by 6 feet facing the point of burst, were erected where the thermal radiation exposure was 17 calories per square centimeter. One of the houses contained rayon drapery, cotton rugs, and clothing, and, as was expected, it burst into flame immediately after the explosion and burned completely. In the other house, the draperies were of vinyl plastic, and rugs and clothing were made of wool. Although much ignition occurred, the recovery party, entering an hour after the explosion, was able to extinguish the fires.

7.60 There is another point in connection with the initiation of fires by thermal radiation that needs consideration. This is the possibility that the flame resulting from the ignition of a combustible material may be subsequently extinguished by the blast wind. It was thought that there was evidence for such an effect from an observation made in Japan (§ 7.67), but this may have been an exceptional case. The matter has been studied, both in connection with the effects in Japan and at various nuclear tests, and the general conclusion is that the blast wind has no significant effect in extinguishing fires (§ 7.68).

Spread of Fires

7.61 The spread of fires in a city, including the development of a "fire storm" to which reference is made in § 7.75, depends upon a variety of conditions, e.g., weather, terrain, and closeness and combustibility of the buildings. Information concerning the growth and spread of fires from a large number of ignition points, such as might follow a nuclear explosion, and their coalescence into large fires (or conflagrations) is limited to the experience of World War II incendiary raids and the two atomic bomb attacks. There is consequently some uncertainty concerning the validity of extrapolating from these limited experiences to the behavior to be expected in other cities. It appears, however, that if other circumstances are more-or-less the same, an important criterion of the probability of fire spread is the distance between buildings. It is evident, from general considerations, that the lower the building density or "built-upness" of an area, the less will be the probability that fire will spread from one structure to another. Furthermore, the larger the spaces between buildings the greater the chances that the fire can be extinguished.

7.62 The curve in Fig. 7.62 gives a rough idea of how the probability of fire spread, expressed as a percentage, depends upon the average distance between buildings in a city. The results will be dependent, to some extent, upon the types of structures involved, e.g., whether they are fire-resistive or not, as well as upon the damage caused by the blast wave. It should be noted that Fig. 7.62 applies to fire spread accompanying a nuclear explosion, when a large number of small fires are started directly by thermal radiation and indirectly in other ways.

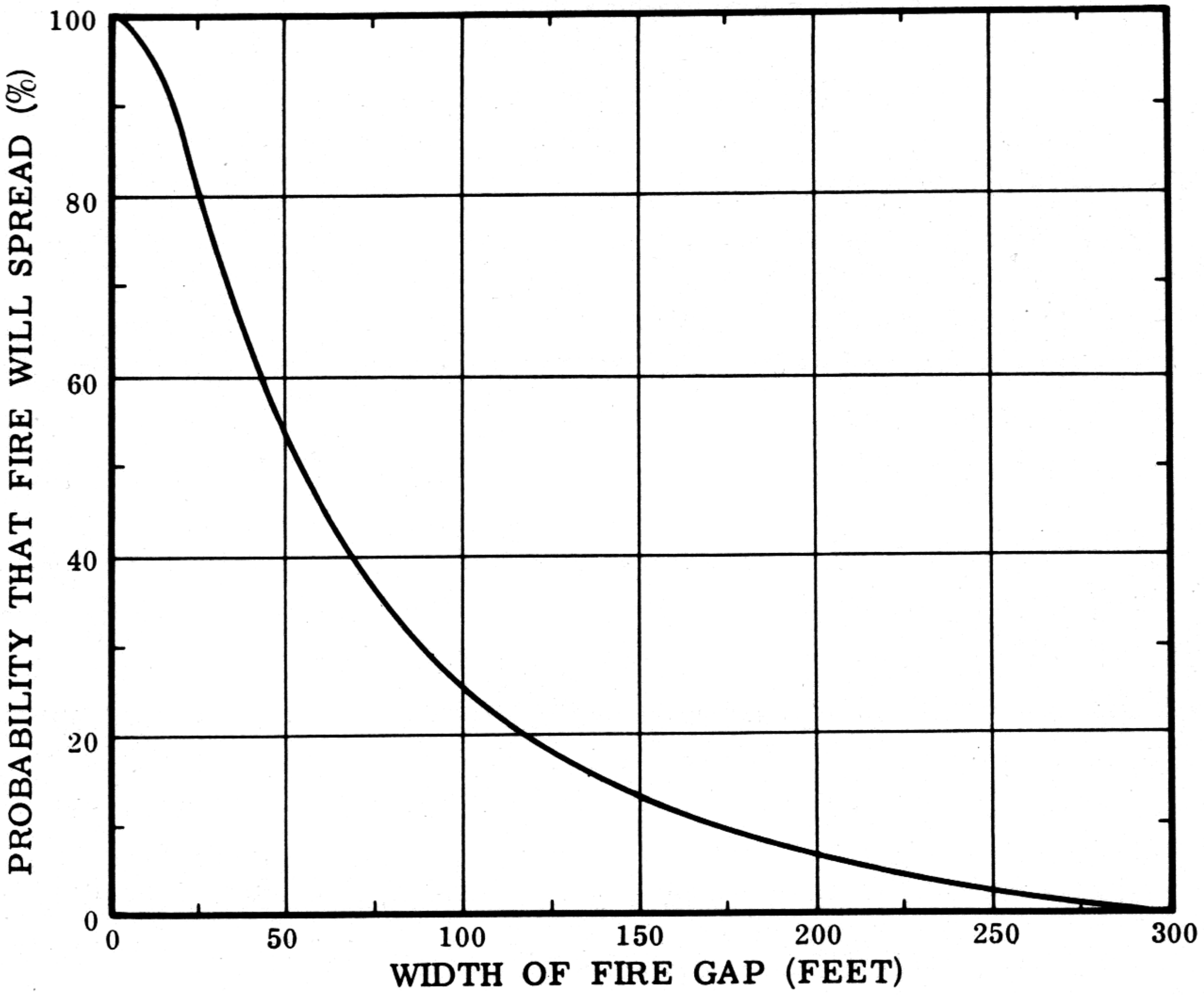

Figure 7.62. Width of gap and probability of fire spread.

7.63 Another aspect of fire spread is the development of mass fires in a forest following primary ignition of dried leaves, grass, and rotten wood by the thermal radiation. Some of the factors which will influence the growth of such fires are the moisture content of the trees, topography, and meteorological conditions. Low atmospheric humidity, strong winds, and steep terrain favor the development of forest fires. In general, a deciduous forest, particularly when in leaf, may be expected to burn less rapidly and with less intensity than a forest of coniferous trees. Green leaves and the trunks of trees would act as shields against thermal radiation, so that the number of points at which ignition occurs in a forest may well be less than would appear at first sight.

INCENDIARY EFFECTS IN JAPAN

THE NUCLEAR BOMB AS AN INCENDIARY WEAPON

7.64 The incendiary effects of a nuclear explosion do not present any especially characteristic features. In principle, the same overall result, as regards destruction by fire and blast, might be achieved by the use of conventional incendiary and high-explosive bombs. It has been estimated, for example, that the fire damage to buildings and other structures suffered at Hiroshima could have been produced by about 1,000 tons of incendiary bombs distributed over the city. It can be seen, however, that since this damage was caused by a single nuclear bomb of only 20 kilotons energy yield, nuclear weapons are capable of causing tremendous destruction by fire, as well as by blast.

7.65 Evidence was obtained from the nuclear explosions over Japan that the damage by fire is much more dependent upon local terrain and meteorological conditions than are blast effects. At both Hiroshima and Nagasaki the distances from ground zero at which particular types of blast damage were experienced were much the same. But the ranges of incendiary effects were quite different. In Hiroshima, for example, the total area severely damaged by fire, about 4.4 square miles, was roughly four times as great as in Nagasaki. One contributory cause was the irregular layout of Nagasaki as compared with Hiroshima; also greater destruction could probably have been achieved by a change in the point of burst. Nevertheless, an important factor was the difference in terrain, with its associated building density. Hiroshima was relatively flat and highly built up, whereas Nagasaki had hilly portions near ground zero that were bare of structures.

ORIGIN AND SPREAD OF FIRES IN JAPAN

7.66 Definite evidence was obtained from Japanese observers that the thermal radiation caused thin, dark cotton cloth, such as the black-out curtains that were in common use during the war, thin paper, and dry, rotted wood to catch fire at distance up to 3,500 feet (0.66 mile) from ground zero (about 35 calories per square centimeter). It was reported that a cedar bark roof farther out was seen to burst into flame, apparently spontaneously, but this was not definitely confirmed. Abnormal enhanced amounts of radiation, due to re-

7.76 It should be noted that the fire storm is by no means a special characteristic of nuclear weapons. Similar fire storms have been reported as accompanying large forest fires in the United States, and especially after incendiary bomb attacks in both Germany and Japan during World War II. The high winds are produced largely by the updraft of the heated air over an extensive burning area. They are thus the equivalent, on a very large scale, of the draft of a chimney under which a fire is burning. Because of limited experience, the conditions for the development of fire storms in cities are not well known. It appears, however, that some, although not necessarily all, of the essential requirements are the following: (1) thousands of nearly simultaneous ignitions over an area of at least a square mile, (2) heavy building density, e.g., more than 20 percent of the area is covered by buildings, and (3) little or no ground wind. Based on these criteria, only certain sections—usually the older and slum areas—of a very few cities in the United States would be susceptible to fire storm development.

7.77 It should be mentioned that no definite fire storm occurred at Nagasaki, although the velocity of the southwest wind, blowing between the hills, increased to 35 miles an hour when the conflagration had become well established, perhaps about 2 hours after the explosion. This wind tended to carry the fire up the valley in a direction where there was nothing to burn. Some 7 hours later, the wind had shifted to the east and its velocity had dropped to 10 to 15 miles per hour. These winds undoubtedly restricted the spread of fire in the respective directions from which they were blowing. The small number of dwellings exposed in the long narrow valley running through Nagasaki probably did not furnish sufficient fuel for the development of a fire storm as compared to the many buildings on the flat terrain at Hiroshima.

TECHNICAL ASPECTS OF THERMAL RADIATION[5]

DISTRIBUTION AND ABSORPTION OF ENERGY FROM THE FIREBALL

7.78 Spectroscopic studies made in the course of weapons tests have shown that the fireball does not behave exactly like a black body, i.e., as a perfect radiator. Generally, the proportion of radiations of longer wave length (greater than 5,500 A)[6] corresponds to higher black body temperatures than does the shorter wave emission. The assumption of black body behavior for the fireball, however, serves as a reasonable approximation in interpreting the thermal

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[5] The remaining sections of this chapter may be omitted without loss of continuity.

[6] The symbol "A" represents the "angstrom", i.e., 10^{-8} cm, the unit in which radiation wave lengths are commonly expressed.

EARLY FALLOUT

9.06 The radiological characteristics of the early fallout from a nuclear weapon are those of the fission products and any induced activity produced. The relative importance of these two sources of residual radiation depends upon the percentage of the total yield that is due to fission, and other factors mentioned in § 9.02. There are, however, two additional factors, namely, "fractionation" and "salting" which may affect the activity of the early fallout; these will be described below.

9.07 As the fireball cools, the fission products and other vapors are gradually condensed on such soil and other particles as are sucked up from below while the fireball rises in the air. For detonations over land, where the particles consist mainly of soil minerals, the fission product vapors condense onto both solid and molten soil particles and also onto other particles that may be present. In addition, the vapors of the fission products may condense with vapors of other substances to form mixed solid particles of small size. In these condensation processes the composition of the fission product mixture may be changed by the phenomenon known as "fractionation." The occurrence of fractionation is shown, for example, by the fact that in a land surface burst the larger particles, which fall out of the fireball at early times and are found near ground zero, have different radiological properties from the smaller particles that leave the radioactive cloud at later times and reach the ground some distance downwind.

9.08 The details of the fractionation process are not well understood, but the effect is related, in part at least, to the presence in the early stages of certain fission products which are inherently gaseous, e.g., krypton and xenon. Subsequently, these radioactive gases decay to form rubidium and cesium, respectively, which can condense onto solid particles. Consequently, the first solid particles to fall out, near ground zero, will be depleted not only in krypton and xenon, but also in their various decay (or daughter) products. On the other hand, small particles which have remained in the cloud for some time will have rubidium and cesium, and their daughters, strontium and barium, condensed upon them. Hence, the more distant fallout will be relatively richer in those elements in which the close fallout is depleted.

9.09 An additional phenomenon which contributes to the fractionation of fission product isotopes is the separation of the elements in the ascending fireball as they condense at different times, corresponding to their different boiling points. Thus the refractory elements can condense at early times in the fireball history, when its temperature is quite high, onto the relatively larger particles which are more abundant at these times. Conversely, volatile elements, with low boiling points, cannot condense until later, when the fireball has cooled and when the larger particle sizes will be depleted. Refractory elements are expected to be relatively more abundant in the close-in early fallout, representing the larger particles, and to be relatively depleted in the more distant portion of the early fallout deposited by smaller particles. The reverse will be true for the more volatile elements. Elements with intermediate boiling points will exhibit behavior between these two extremes.

9.10 For detonations of large energy yield at or near the surface of the sea, where the condensed particles consist of sea-water salts and water, fractionation of the fallout is usually very small. The reason is that the fireball must cool to 100° C (212° F) or less before the evaporated water condenses. The long cooling time and the presence of very small water droplets permit removal from the radioactive cloud of the daughters of the gaseous krypton and xenon along with the other fission products. In this event, there is little or no variation in composition of the radioactive fallout (or rainout) with distance from the explosion.

9.11 The composition of the fallout can also be changed by "salting" the weapon to be detonated. This consists in the inclusion of significant quantities of certain elements, possibly enriched in specific isotopes, for the purpose of producing induced radioactivity. There are several reasons why a weapon might be salted. For example, salting has been used in some weapons tests to provide radioactive tracers for various purposes, such as the study of the paths and relative compositions of the early and delayed stages of fallout. By the choice of elements, to give radioactive products of suitable half lives and radioactivity, the characteristics of the early fallout from a nuclear weapon could be modified for application in radiological warfare (§ 9.110).

ACTIVITY AND DECAY OF EARLY FALLOUT

9.12 As stated in Chapter I, the fission products constitute a very complex mixture of over 200 different forms (isotopes) of 36 elements. Most of these isotopes are radioactive, decaying by the emission of beta particles, frequently accompanied by gamma radiation. About 2 ounces of fission products are formed for each kiloton (or 125 pounds per megaton) of fission energy yield. The total

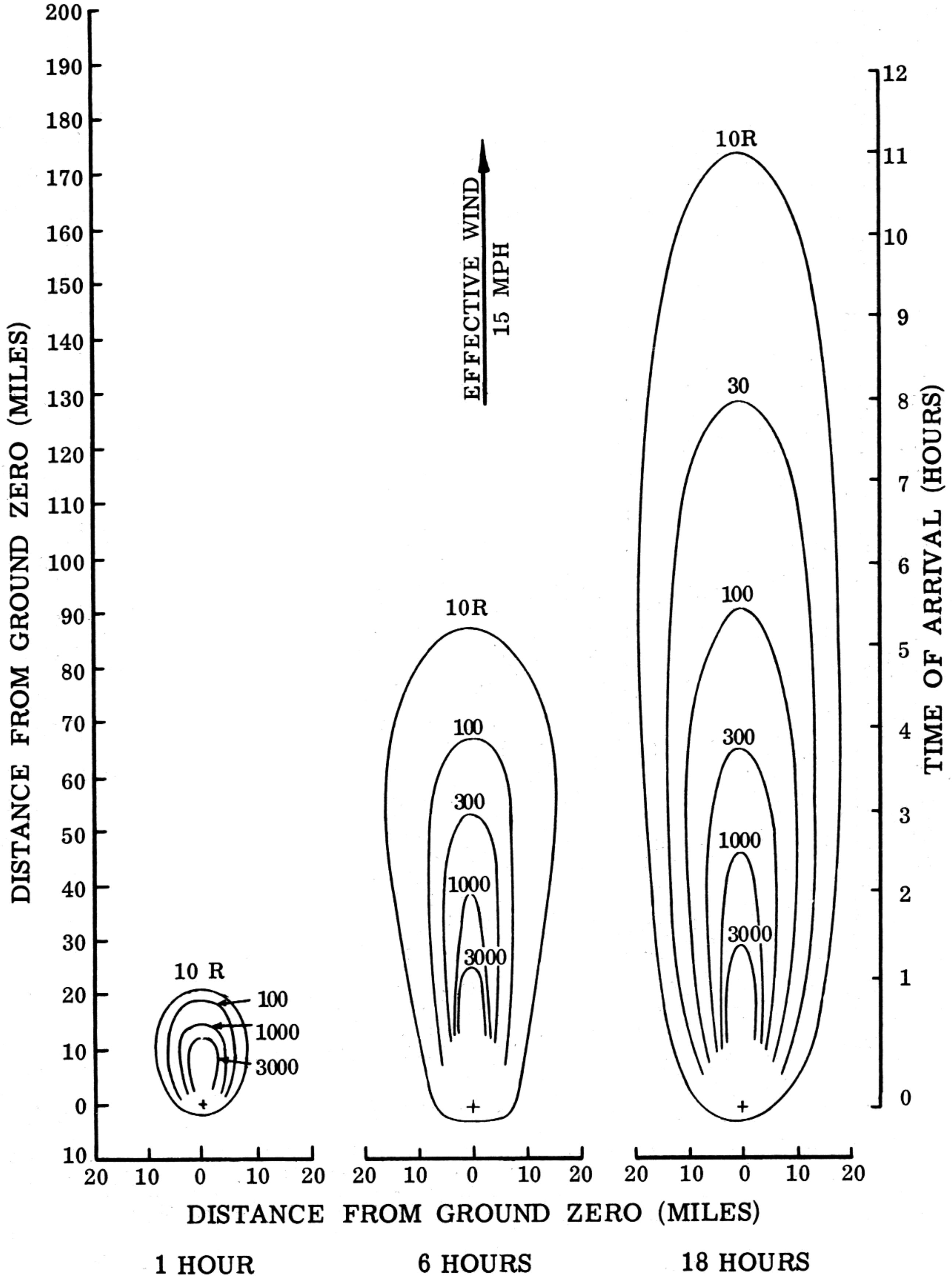

Figure 9.67b. Total-dose contours from early fallout at 1, 6, and 18 hours after surface burst with 1-megaton fission yield (15 mph effective wind speed).

is then due to the natural decay of the fission products. Turning to Fig. 9.67b, it is seen that the total radiation dose received at the given location by 1 hour after the explosion is small, because the fallout has only just started to arrive. By 6 hours, the total dose has injury would have depended upon evacuation of the area or taking protective measures. 15 Mt BRAVO test

9.101 The BRAVO shot is of particular interest because the predicted fallout patterns for megaton-range explosions, such as those given in §9.67 and §9.73, are largely based on inferences drawn from measurements made after this detonation. The available data, for the estimated total doses received at various locations at 96 hours after the explosion, are shown by the points in Fig. 9.101. Through these points there have been drawn a series of contour lines which appear to be in reasonably good agreement with the data. However, other patterns are possible; one, for example, ascribes the large radiation doses on the northern islands of Rongelap Atoll to a hot spot and brings the 3,000-roentgen contour line in much closer to Bikini Atoll. Because of the absence of observations from large areas of ocean, the choice of the fallout pattern, such as the one in Fig. 9.101, is largely a matter of guesswork. Nevertheless, one fact is certain: there was appreciable radioactive contamination at distances downwind of 300 miles or more from the explosion.

9.102 It should be noted that the doses to which the contours in Fig. 9.101 refer are values calculated from instrument records. They represent the maximum possible exposure and would be received only by those individuals who remained in the open, with no protection against the radiation, for the whole time. Any kind of shelter, e.g., within a building, or evacuation of the area would have reduced the dose received. On the other hand, persons remaining in the area for a period longer than 96 hours after the explosion would have received larger doses of the residual radiation.

9.103 A radiation dose of 700 roentgens spread over a period of 96 hours would probably prove fatal in the great majority of cases. It would appear, therefore, that following the test explosion of March 1, 1954, there was sufficient radioactivity from the fallout in a downwind belt about 170 miles long and up to 35 miles wide to have seriously threatened the lives of nearly all persons who remained in the area for at least 96 hours following the detonation without taking protective measures of any kind. At distances of 300 miles or more downwind, the number of deaths due to short-term radiation effects would have been negligible, although there would probably have been many cases of sickness resulting in temporary incapacity.

9.104 The period of 96 hours after the explosion, for which Fig. 9.101 gives the accumulated radiation exposures, was chosen somewhat arbitrarily. It should be understood, however, as has been frequently stated earlier in this chapter, that the radiations from the

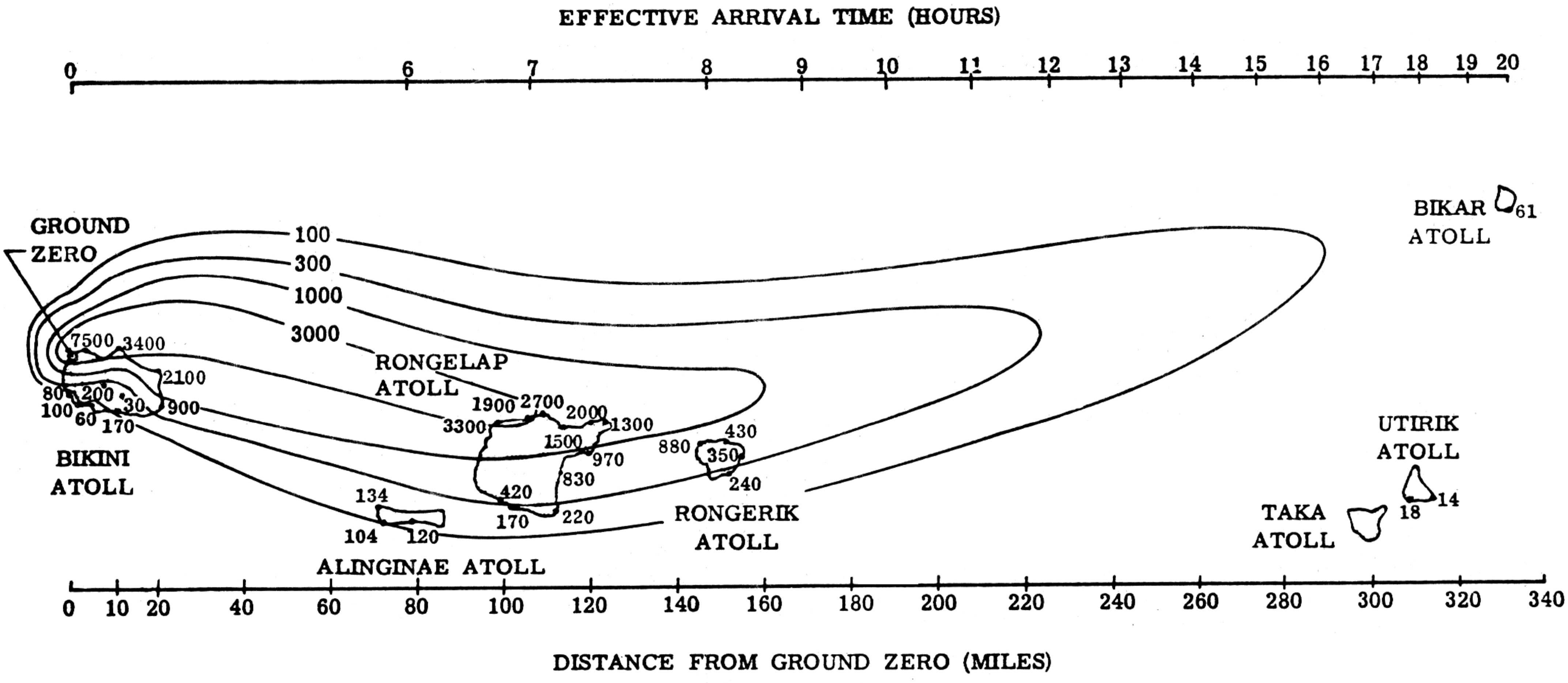

Figure 9.101. Estimated total-dose contours in roentgens at 96 hours after the BRAVO test explosion.

fallout will continue to be emitted for a long time, although at a gradually decreasing rate. The persistence of the external gamma radiation may be illustrated in connection with the BRAVO test by considering the situation at two different locations in Rongelap Atoll. Fallout began about 4 to 6 hours after the explosion and continued for several hours.

9.105 The northwestern tip of the atoll, 100 miles from the point of detonation, received 3,300 roentgens during the first 96 hours after the fallout started. This was the heaviest fallout recorded at the same distance from the explosion and may possibly have represented a hot spot, as mentioned above. About 25 miles south, and 115 miles from ground zero, the dose over the same period was only 220 roentgens. The inhabitants of Rongelap Atoll were in this area, and were exposed to radiation dosages up to 175 roentgens before they were evacuated some 44 hours after the fallout began (see § 11.126). The maximum theoretical exposures in these two areas of the atoll for various time intervals after the explosion, calculated from the decay curves given earlier in this chapter, are recorded in Table 9.105.

TABLE 9.105

CALCULATED RADIATION DOSES AT TWO LOCATIONS IN RONGELAP ATOLL FROM FALLOUT FOLLOWING THE MARCH 1, 1954 TEST AT BIKINI

	Accumulated dose in this period (roentgens)	
Exposure period after the explosion	*Inhabited location*	*Uninhabited location*
First 96 hours	220	3, 300
96 hours to 1 week	35	530
1 week to 1 month	75	1, 080
1 month to 1 year	75	1, 100
Total to 1 year	405	6, 010
1 year to infinity	About 8	About 115

9.106 It must be emphasized that the calculated values in Table 9.105 represent the maximum doses at the given locations, since they are based on the assumption that exposed persons remain out-of-doors for 24 hours each day and that no measures are taken to remove radioactive contamination. Furthermore, no allowance is made for weathering or the possible dispersal of the particles by winds. For example, the dose rates measured on parts of the Marshall Islands on the 25th day following the explosion were found to be about 40 percent of the expected values. Rains were known to have occurred during the second week, and these were probably responsible for the major decrease in the contamination.

TABLE 9.139

PROTECTION FACTOR RANGES FOR VARIOUS STRUCTURES

Type of structure	*Protection factor range*
Underground shelters (3 ft earth cover or equivalent). Sub-basements of multistory buildings.*	1,000 or greater
Basement fallout shelters (heavy masonry residences). Basements without exposed walls of multistory masonry buildings. Central areas of upper floors (excluding top 3 floors) of high-rise buildings † with heavy floors and exterior walls.	250 to 1,000
Basement fallout shelters (frame and brick veneer residences). Central areas of basements with partially exposed walls in multistory buildings. Central areas of upper floors (excluding top floor) of multistory buildings with heavy floors and exterior walls.	50 to 250
Basements without exposed walls of small 1- or 2-story buildings. Central areas of upper floors (excluding top floor) of multistory buildings with light floors and exterior walls.	10 to 50
Basements (partially exposed) of small 1- or 2-story buildings. Central areas on ground floor in 1- or 2-story buildings with heavy masonry walls.	2 to 10
Above ground areas of light residential structures.	2 or less

* Multistory buildings are those having from 3 to about 10 stories.
† High-rise buildings have more than about 10 stories.

arises from the possible exposure to gamma rays from sources outside the body, with the effect of beta particles from fallout material in direct contact with the skin as secondary. Because most of the radioisotopes in the early fallout have relatively short half-lives, the activity decays fairly rapidly and will have decreased by a factor of several thousand after 6 months (or less). The delayed fallout hazard, on the other hand, is due to radioactive material, particularly strontium-90, which is ingested as food. The strontium-90 accumulates in the bone and part may remain there for many years, representing a prolonged internal hazard. Both early and delayed fallout can have long-term genetic effects, but they are probably of less significance than other deleterious effects to be expected. These and related aspects of fallout are discussed more fully in Chapter XI.

9.142 The very fine particles present in the radioactive cloud, with radii of a few microns or less (§ 9.47), fall extremely slowly under the influence of gravity. Consequently, they remain suspended in the zero at which there was 50-percent survival (for at least 20 days) among the occupants of a number of buildings in Hiroshima. School personnel who were indoors had a much higher survival probability than those who were outdoors at the times of the explosions.

TABLE 11.17

AVERAGE DISTANCES FOR 50-PERCENT SURVIVAL AFTER 20 DAYS IN HIROSHIMA

Conditions	*Approximate distance (miles)*
Overall	0. 8
Concrete buildings	0. 12
School personnel:	
Indoors	0. 45
Outdoors	1. 3

CAUSES OF INJURIES AMONG SURVIVORS

11.18 From surveys made of a large number of Japanese, a fairly good idea has been obtained of the distribution of the three types of injuries among those who became casualties but survived the nuclear attacks. The results are quoted in Table 11.18. It will be observed that the totals add up to more than 100 percent, since many individuals suffered multiple injuries.

TABLE 11.18

DISTRIBUTION OF TYPES OF INJURY AMONG SURVIVORS

Injury	*Percent of survivors*
Blast (mechanical)	70
Burns (flash and flame)	65
Nuclear radiation (initial)	30

11.19 Among survivors the proportion of indirect blast (mechanical) injuries due to flying missiles and movement of other debris was smallest outdoors and largest in certain types of industrial buildings. Patients were treated for lacerations received out to 10,500 feet (2 miles) from ground zero in Hiroshima and out to 12,500 feet (2.2 miles) in Nagasaki. These distances correspond roughly to those at which moderate damage occurred to wood-frame houses, including the shattering of window glass.

11.20 An interesting observation made among the Japanese survivors was the relatively low incidence of serious mechanical injuries.

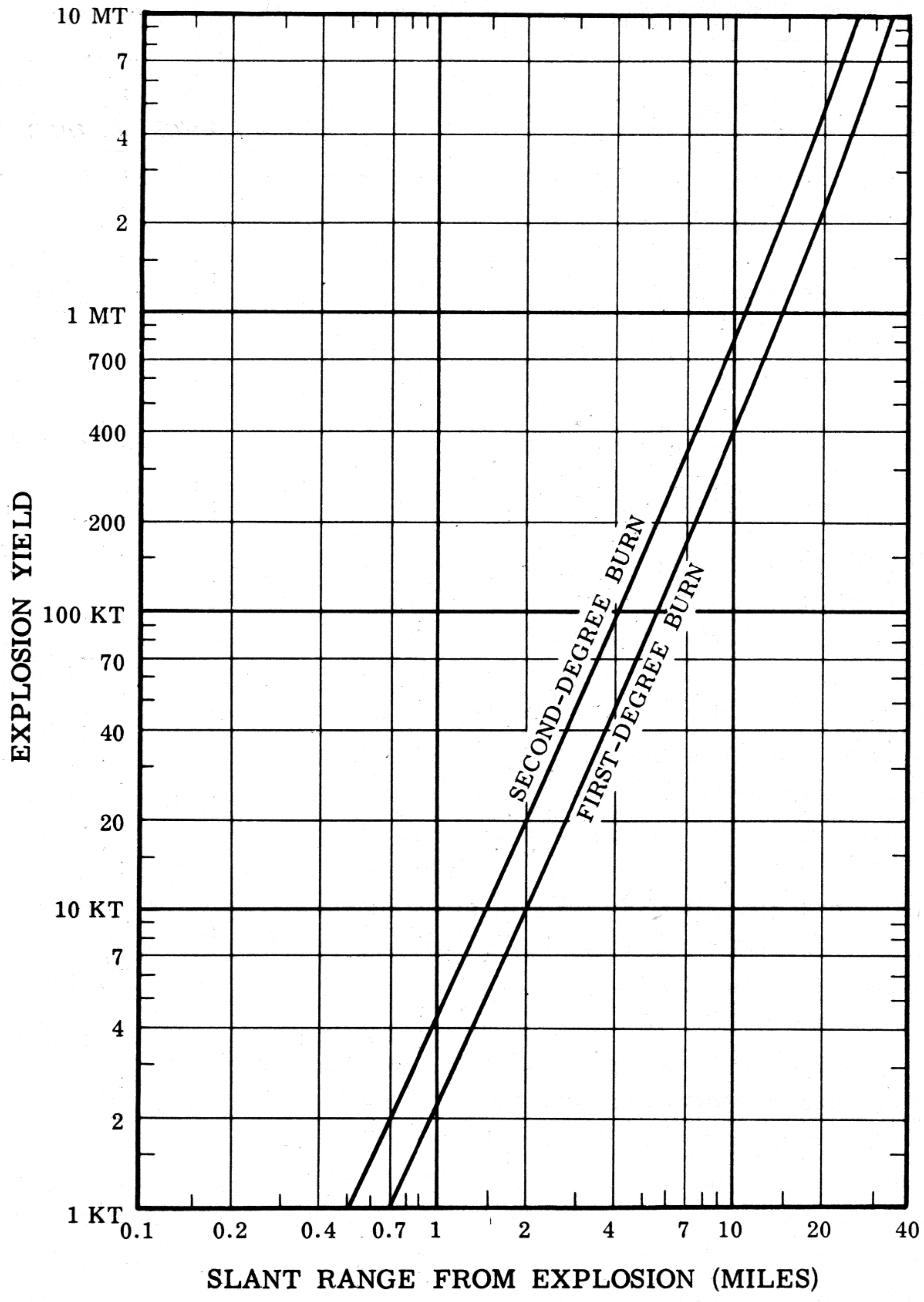

Figure 11.63. Ranges for first- and second-degree burns as a function of the total energy yield.

11.67 Investigators have reported that in no case, among 1,400 examined, was the thermal radiation exposure of the eyes apparently sufficient to produce permanent opacity of the cornea. This observation is not surprising since the cornea is transparent to the major portion of the thermal energy which is received in the visible and longer wavelength (infrared) parts of the spectrum. In approximately one-quarter of the cases studied there had been facial burns and often singeing of the eyebrows and eyelashes. Nevertheless, some 3 years later the corneas were found to be normal. ← NO EYES BURNED OUT.

11.68 Several reasons have been suggested for the scarcity of severe eye injuries in Japan. For example, the detonations occurred in the morning in broad daylight when the eye pupil would be expected to be small. Another possible explanation is that the recessed position of the eyes and, in particular, the overhanging upper lids served to decrease the direct exposure to thermal radiation. Furthermore, on the basis of probability, it is likely that only a small proportion of individuals would be facing the explosions in such a way that the fireball would actually be in their field of vision.

11.69 The effects of thermal radiation on the eyes fall into two main categories: (1) permanent (chorioretinal burns) and (2) temporary (flash blindness). Concentration of sufficient direct thermal energy, due to the focusing action of the eye lens, can cause the permanent damage. The focusing occurs, however, only if the fireball is in the individual's field of view. When this happens, chorioretinal burns may be experienced at distances from the explosion which exceed those where the thermal radiation produces skin burns. As a result of accidental exposures at nuclear weapons tests, a few burns of this type have been received at distances up to 10 miles from explosions of approximately 20-kilotons energy yield.

11.70 Experiments have been made with rabbits in an attempt to estimate the susceptibility of the human eye to thermal radiation. Although the rabbit eye is smaller, it is similar to the human eye in many respects including pupillary opening. However, under the same exposure conditions, the rabbit retina receives a larger amount of radiant energy per unit area because the rabbit eye, being smaller and having a shorter focal length, produces a smaller image. Estimates of the limiting distances are given in Table 11.70 for chorioretinal burns associated with a 20-kiloton low air burst, based on tests with rabbits and the assumption that, in humans, an exposure of 0.1 calorie per square centimeter for a period of about 0.15 second would produce a minimal eye burn. It should be noted, however, that research suggests this assumption may not be entirely correct. The distances are given for various degrees of atmospheric visibility, as defined in § 7.12, and for different pupil diameters. The importance of the air visibility and the brightness to which the eye is adapted are apparent.

TABLE 11.70

ESTIMATED LIMITING DISTANCES FOR CHORIORETINAL BURNS IN HUMANS FOR A 20-KILOTON LOW AIR BURST

	Pupil Opening Diameter		
	2 mm (Bright sunlight adapted	*4 mm (Cloudy day)*	*8 mm (Completely dark adapted)*
Visibility (miles)	*Distance (miles)*		
25	23	31	40
12	11	16	20
6	6	8	10
2	2	3	4

11.71 The size of the eye lesion produced is uncertain since it depends on the distance from the explosion and severity of the damage. The lesions contain areas of different types and degrees of damage; their relations to yield depend on a variety of factors and cannot be established with the information available at present. In all instances, however, there will be some temporary loss of visual acuity, at least, but the ultimate effect will depend upon the severity of the exposure and, to a greater extent, upon its location. If a chorioretinal burn is mild, or on the periphery of the visual field, the acuity may hardly be affected, but in more serious or centrally located cases there may be considerable loss of vision.

11. 72 In a high-altitude detonation, the thermal radiation will generally traverse less of the atmosphere than for an air burst at the same slant range. Consequently, the atmospheric attenuation will be less in the former case in the absence of clouds, and chorioretinal burns may be expected at greater distances from the point of burst for similar energy yields. In order to obtain data concerning the possibility of eye injury, rabbits were exposed to the radiation from the TEAK shot of a megaton-range weapon at an altitude of 252,000 feet (§§ 2.53, 2.123 *et seq.*). Under nighttime conditions, chorioretinal burns occurred at slant distances up to about 345 miles; however, no measurements were made at greater distances and so this cannot be considered as a threshold range for eye damage.

11.73 Although extrapolation of the rabbit data to man is uncertain for high-altitude shots, it is felt that there would be some danger to human beings at distances greater than 200 miles under similar circumstances, and possibly as far as the eye can see at high altitude. It may be concluded from the Japanese situations that the number of individuals who will be looking directly at the fireball in the event of an unexpected air burst will not be large. High-altitude detonations will be visible over greater distances and so it is probable that more people would actually observe an explosion of this type.

11.74 The size of the fireball image on the retina decreases with increasing slant range from the burst point and hence the radiant energy is received on a smaller area of the retina. The decrease in area largely compensates for the decrease in thermal energy, which varies inversely as the square of the distance from the explosion. In these circumstances, therefore, the thermal energy received per unit area of the retina decreases only as the atmospheric transmittance decreases with increasing distance (§ 7.104). However, because of chromatic aberration, the image on the retina does not become much less than about 10 microns (0.001 cm) in diameter. Consequently, beyond a certain distance from the explosion, the image of the fireball does not decrease further. The radiant exposure then decreases rapidly with increasing distance since it is dependent on both the inverse square of the distance and the atmospheric transmittance.

11.75 Temporary "flash blindness" or "dazzle" can occur in persons who are too far from the explosion to suffer chorioretinal injury or who do not view the fireball directly. Flash blindness results when more thermal energy is received on the retina than is necessary for image perception, but less than is required for burn. The effect is a localized bleaching of the visual elements, with image persistence, after-image formation, halo, etc. From a few seconds to several days may be required for the eye to recover its functions. Dazzle is essentially the same as flash blindness although some authorities reserve the term dazzle for the effect of scattered light reaching the eye in which recovery is much more rapid than with "line of sight" flash blindness. Flash blindness occurs at greater ranges at night, when the eye is dark adapted, than in daylight; however, the range of these effects is highly dependent on atmospheric conditions prevailing at the time of detonation.

11.76 Much of the thermal radiation responsible for chorioretinal burns and flash blindness would arrive so soon after the explosion of a weapon in the kiloton energy range that reflex actions, such as blinking and contraction of the eye pupil, can give only limited protection. The same holds true for high-altitude, kiloton and megaton yield detonations, in which most of the thermal energy is emitted in very short times (§ 7.96). In certain situations with air bursts of high yield, however, the thermal pulse is long enough to permit some protection by the blink reflex.

11.149 Valuable information concerning the development and healing of beta burns has been obtained from observations of the Marshall Islanders who were exposed to fallout in March 1954. Within about 5 hours of the burst, radioactive material commenced to fall on some of the islands. Although the fallout was observed as a white powder, consisting largely of particles of lime (calcium oxide) resulting from the decomposition of coral (calcium carbonate) by heat, the island inhabitants did not realize its significance. Because the weather was hot and damp, the Marshallese remained outdoors; their bodies were moist and they wore relatively little clothing. As a result, appreciable amounts of fission products fell upon the hair and skin and remained there for a considerable time. Moreover, since the islanders, as a rule, did not wear shoes, their bare feet were continually subjected to contamination from fallout on the ground.

11.150 During the first 24 to 48 hours, a number of individuals in the more highly contaminated groups experienced itching and a burning sensation of the skin. These symptoms were less marked among those who were less contaminated with early fallout. Within a day or two all skin symptoms subsided and disappeared, but after the lapse of about 2 to 3 weeks, epilation and skin lesions were apparent on the areas of the body which had been contaminated by fallout particles. There was apparently no erythema, either in the early stages (primary) or later (secondary), as might have been expected, but this may have been obscured by the natural coloration of the skin.

11.151 The first evidence of skin damage was increased pigmentation, in the form of dark colored patches and raised areas (macules, papules, and raised plaques). These lesions developed on the exposed parts of the body not protected by clothing, and occurred usually in the following order: scalp (with epilation), neck, shoulders, depressions in the forearm, feet, limbs, and trunk. Epilation and lesions of the scalp, neck, and foot were most frequently observed (Figs. 11.151 a and b).

11.152 In addition, a bluish-brown pigmentation of the fingernails was very common among the Marshallese and also among American Negroes. The phenomenon appears to be a radiation response peculiar to the dark-skinned races, since it was not apparent in any of the white Americans who were exposed at the same time. The nail pigmentation occurred in a number of individuals who did not have skin lesions. It is probable that this was caused by gamma rays, rather than by beta particles, as the same effect has been observed in dark-skinned patients undergoing X-ray treatment in clinical practice.

11.153 Most of the lesions were superficial without blistering. Microscopic examination at 3 to 6 weeks showed that the damage

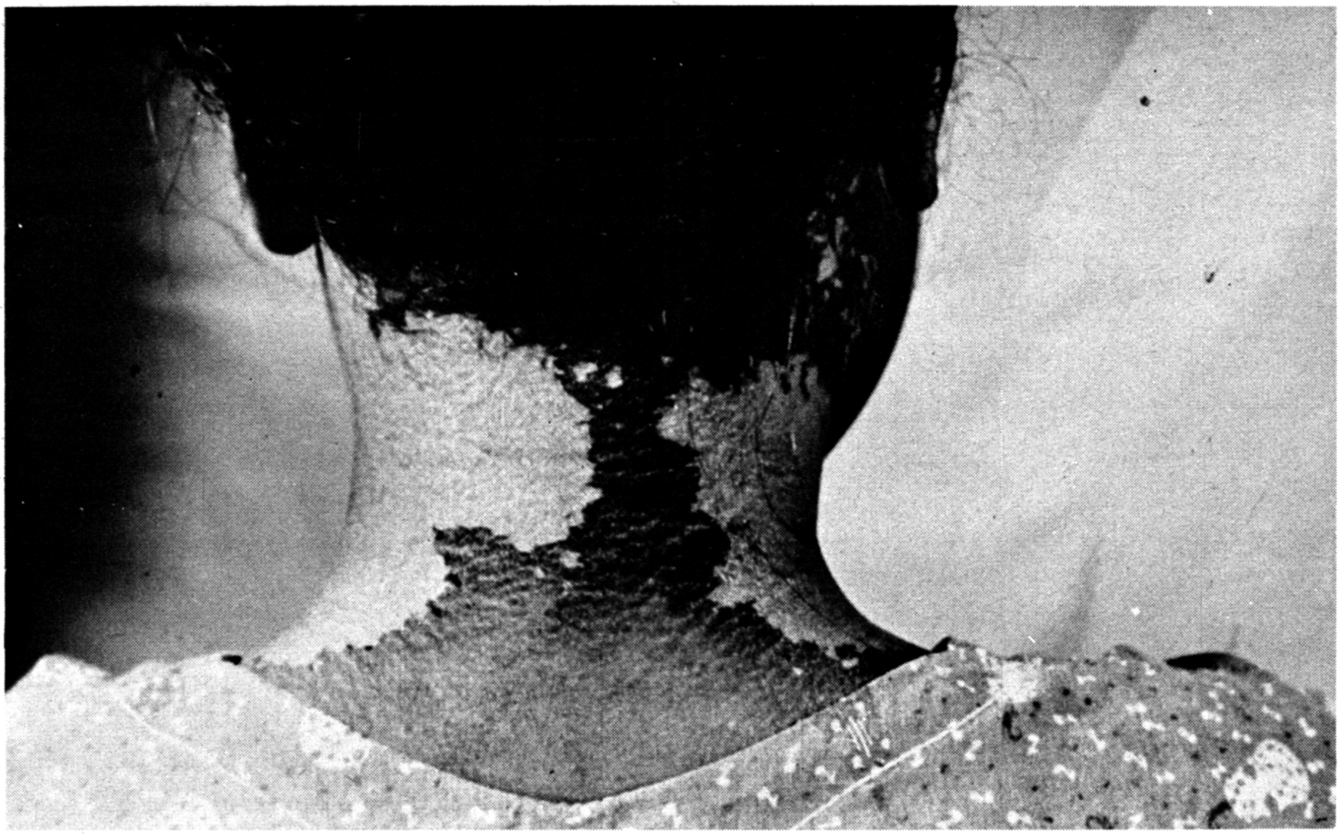

Figure 11.151a. Beta burn on neck 1 month after exposure.

was most marked in the outer layers of the skin (epidermis), whereas damage to the deeper tissue was much less severe. This is consistent with the short range of beta particles in animal tissue. After formation of dry scab, the lesions healed rapidly leaving a central depigmented area, surrounded by an irregular zone of increased pigmentation. Normal pigmentation gradually spread outward in the course of a few weeks.

11.154 Individuals who had been more highly contaminated developed deeper lesions, usually on the feet or neck, accompanied by mild burning, itching, and pain. These lesions were wet, weeping, and ulcerated, becoming covered by a hard, dry scab; however, the majority healed readily with the regular treatment generally employed for other skin lesions not connected with radiation. Abnormal pigmentation effects persisted for some time, and in several cases about a year elapsed before the normal (darkish) skin coloration was restored (Figs. 11.154 a and b).

11.155 Regrowth of hair, of the usual color (in contrast to the skin pigmentation) and texture, began about 9 weeks after contamination and was complete in 6 months. By the same time, nail discoloration had grown out in all but a few individuals. Seven years later, there were only 10 cases which continued to show any effects of beta burns, and there was no evidence of malignant changes.

Figure 11.151b. Beta burn on feet 1 month after exposure.

Blood studies of platelets and red blood cells indicated levels lower than average at 5 years after exposure; at 7 years after exposure the platelets continued to be slightly depressed. It thus appears that repair of bone marrow injury was not complete at this time. In the 1961 examination of the Marshallese people there was a possible indication of bone growth retardation in children who were babies at the time of the explosion.

INTERNAL HAZARD

11.156 Wherever fallout occurs there is a chance that radioactive material will enter the body through the digestive tract (due to the

Figure 11.154a. Beta burn on neck 1 year after exposure (see Fig. 11.151a).

consumption of food and water contaminated with fission products), through the lungs (by breathing air containing fallout particles), or through wounds or abrasions. It should be noted that even a very small quantity of radioactive material present in the body can produce considerable injury. Radiation exposure of various organs and tissues from internal sources is continuous, subject only to depletion of the quantity of active material in the body as a result of physical (radioactive decay) and biological (elimination) processes. Furthermore, internal sources of alpha emitters, e.g., plutonium, or of beta

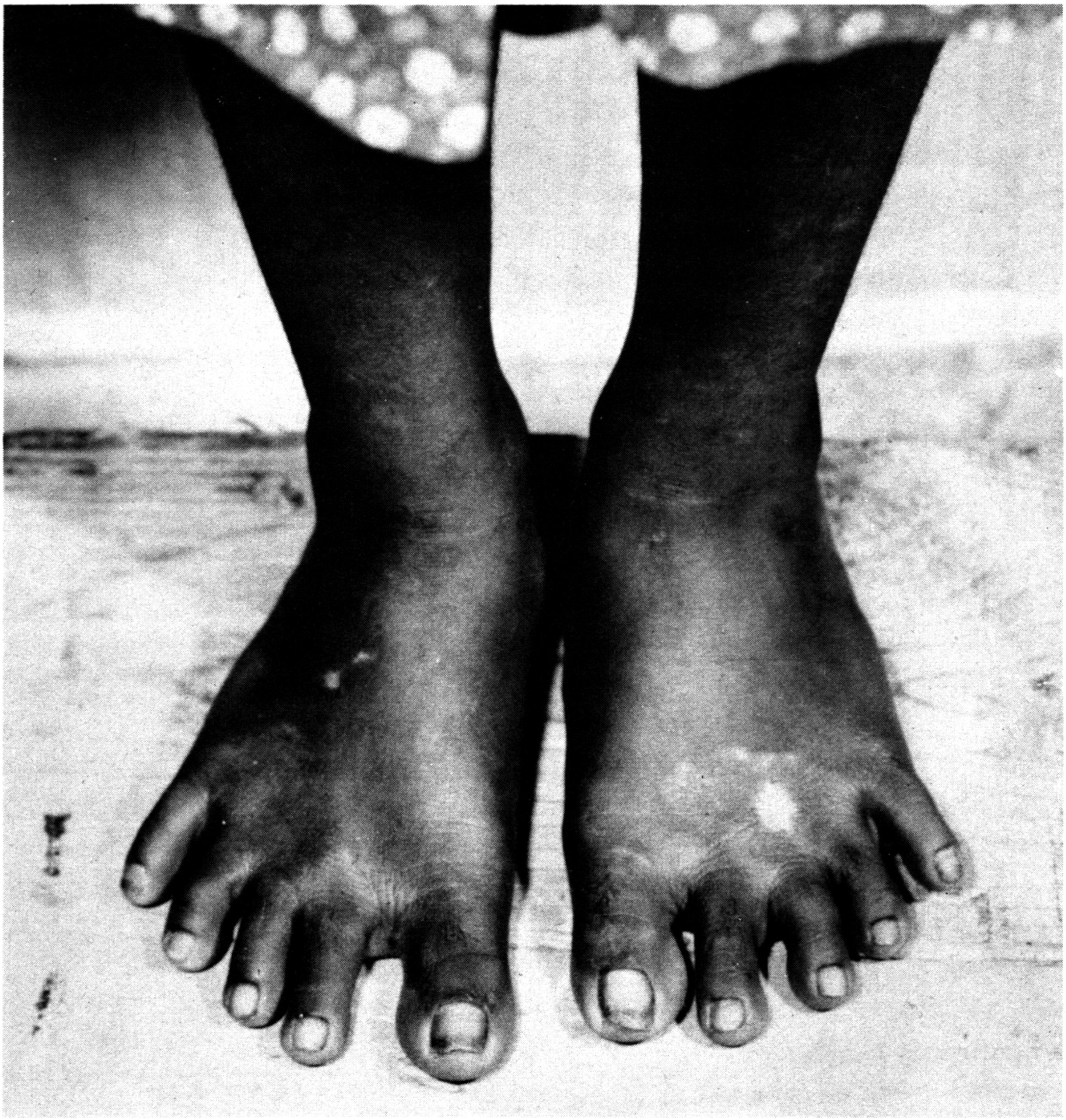

Figure 11.154b. Beta burn on feet 6 months after exposure (see Fig. 11.151b).

particles, or soft (low-energy) gamma-ray emitters, can dissipate their entire energy within a small, possibly sensitive, volume of body tissue, thus causing considerable damage.

11.157 The situation just described is sometimes aggravated by the fact that certain chemical elements tend to concentrate in specific cells or tissues, some of which are highly sensitive to nuclear radiation. The fate of a given radioactive element which has entered the blood stream will depend upon its chemical nature. Radioisotopes of an element which is a normal constituent of the body will follow the same metabolic processes as the naturally occurring, inactive (stable) isotopes of the same element. This is the case, for example, with iodine which tends to concentrate in the thyroid gland.

11.158 An element not usually found in the body, except perhaps in minute traces, will behave like one with similar chemical properties that is normally present. Thus, among the absorbed fission products, strontium and barium, which are similar chemically to calcium, are largely deposited in the calcifying tissue of bone. The radioisotopes of the rare earth elements, e.g., cerium, which constitute a considerable proportion of the fission products, and plutonium, which may be present to some extent in the fallout, are also "bone-seekers." Since they are not chemical analogues of calcium, however, they are deposited to a smaller extent and in other parts of the bone than are strontium and barium. Bone-seekers, are, nevertheless, potentially very hazardous because they can injure the sensitive bone marrow where many blood cells are produced. The damage to the blood-forming tissue thus results in a reduction in the number of blood cells and so affects the entire body adversely.

11.159 The extent to which early fallout contamination can get into the blood stream will depend upon two main factors: (1) the size of the particles, and (2) their solubility in the body fluids. Whether the material is subsequently deposited in some specific tissue or not will be determined by the chemical properties of the elements present, as indicated previously. Elements which do not tend to concentrate in a particular part of the body are eliminated fairly rapidly by natural processes.

11.160 The amount of radioactive material absorbed from early fallout by inhalation appears to be relatively small. The reason is that the nose can filter out almost all particles over 10 microns (0.001 centimeter) in diameter, and about 95 percent of those exceeding 5 microns (0.0005 centimeter). Most of the particles descending in the fallout during the critical period of highest activity, e.g., within 24 hours of the explosion, will be considerably more than 10 microns in diameter (§ 9.186 *et seq*). Consequently, only a small proportion of the early fallout particles present in the air will succeed in reaching the lungs. Furthermore, the optimum size for passage from the alveolar (air) space of the lungs to the blood stream is as small as 1 to 2 microns. The probability of entry into the circulating blood of fission products and other weapon residues present in the early fallout, as a result of inhalation, is thus low. Any very small particles reaching the alveolar spaces may be retained there or they may be removed either by physical means, e.g., by coughing, or by the lymphatic system to lymph nodes in the mediastinal (middle chest) area, where they may accumulate.

Although genetic damage is cumulative, it is now recognized that the rate at which changes result from exposure to radiation is somewhat dependent on the dose rate. Prompt, high dose rate exposures (greater than 25 rads per minute) may be at least four times as effective as are continuous exposures at low dose rates (1 rad or less per minute), for the same total dose. Thus, the protracted exposure that could result from a low-dose fallout field would presumably not carry the same threat of genetic change as would exposure to a single high-intensity dose, e.g., from the initial nuclear radiation, although the total dose delivered may be the same in both cases.

11.192 The mechanism of heredity, which is basically similar in sexually reproducing plants and animals, including man, is somewhat as follows. The nuclei of dividing cells contain a definite number of thread-like entities called "chromosomes" which are visible under the microscope. These chromosomes are believed to be differentiated along their length into thousands of distinctive units, referred to as "genes." The chromosomes (and genes) exist in every cell of the body, but from the point of view of genetics (or heredity), it is only those in the germ cells, present in the reproductive organs, that are important.

11.193 Human body cells normally contain 46 chromosomes, made up of two similar (but not identical) sets of 23 chromosomes each. One of these sets was inherited from the mother, for the egg cell (produced in the ovaries) carries a set of 23 chromosomes, whereas the other set came from the father, for the sperm cell (produced in the testes) carries a set of 23 similar (but not identical) chromosomes. As the individual develops, following upon the fusion of the original egg and sperm cells, the chromosomes and genes are, in general, duplicated without change.

11.194 In rare instances, however, a deviation from normal behavior occurs and instead of a chromosome duplicating itself in every respect, there is a change in one or more of the genes. This change, called a "mutation," is essentially permanent, for the mutant gene is reproduced in its altered form. If this mutation occurs in a body cell, there may be some effect on the individual, but the change is not passed on. However, if the mutation occurs in a germ cell of either parent, a new characteristic may appear in a later generation. The mutations which occur naturally, without any definitely assignable cause or human intervention, are called "spontaneous mutations."

11.195 The matter of immediate interest is that the frequency with which mutations occur can be increased in various ways, one being by exposure of the sex glands (or "gonads"), i.e., testes or ova-

CHAPTER XII

PRINCIPLES OF PROTECTION

BASIS FOR PROTECTIVE ACTION

INTRODUCTION

12.01 In the preceding chapters the phenomena and the destructive effects of nuclear explosions have been described in terms that are reasonably exact. In addition, the best available assessment of these effects on man have been presented. But in planning protection from the consequences of a nuclear explosion, so many uncertainties are encountered that precise analysis of a particular situation is impractical. For example, it is impossible to know in advance where or when a weapon will be detonated and what will be the explosive energy or the kind of burst. Nevertheless, there are some basic principles which, if properly understood and applied, could provide a measure of protection to a large proportion of the population in the event of a nuclear attack.

12.02 The most fruitful application of the principles of protection requires considerable preplanning on the part of individuals; however, some protection may be possible even in certain emergency situations if the principles are understood beforehand. It is the purpose of this chapter to present the quantitative aspects of weapons effects in a simplified form and to use them to explain the principles of protection. The information provided should be helpful in indicating the nature of the protection required and what steps must be taken in advance to achieve such protection. However, details of specific measures are not included since they are described in other publications.[1]

12.03 In the following sections the various effects of a nuclear explosion will be reviewed, with special reference to their ranges, and the principles of protection against each of these effects will be examined. At the same time, it will be shown how the measures used to provide protection from one particular effect can furnish protection against

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[1] See the bibliography at the end of the chapter.

others, so that the problem is less complicated than it might at first appear. Finally, a brief discussion will be presented of the planning needed to implement the principles of protection so as to make them effective.

IMMEDIATE AND DELAYED EFFECTS

12.04 The effects of a nuclear explosion may be divided into two broad categories, namely, immediate and delayed. The immediate effects are those which occur within a few minutes of the actual explosion. These include air blast and ground shock, thermal radiation (light and heat), and initial nuclear radiation.

12.05 The delayed effects are associated with the radioactivity present in fallout and neutron-induced radioactivity. The early fallout from a surface burst will begin to reach the ground within a few minutes after the explosion at close-in locations, and at increasingly later times at greater distances from ground zero, depending on the effective wind speed and direction. At distances of several hundred miles from the explosion, the fallout may not commence until as late as 24 hours after the burst time. Furthermore, several hours may elapse between the time of arrival of the fallout at any point and the time when deposition is essentially complete. A significant early fallout is associated with a surface burst or a subsurface burst which vents to the atmosphere, but not with an air burst or with a completely contained underground burst. Neutron-induced radioactivity, apart from that in the weapons residues, extends only a short distance from ground zero and it decays more rapidly than fallout.

12.06 Except for a contained burst, all presently known nuclear weapons produce delayed (world-wide) fallout. However, this part of the fallout is generally not apparent until several weeks or months have elapsed; it will not be treated here, since the present discussion refers to protection which is effective at the time of, and soon after, an explosion.

RANGES OF VARIOUS IMMEDIATE EFFECTS

12.07 When a nuclear weapon of known yield is detonated on the surface, at a particular height in the air, or at a particular depth below the surface, the ranges of the immediate effects are fairly well defined. For example, there will be an area surrounding ground zero within which the destruction due to blast and shock, and accompanying fires, will be so great that the survival of inhabitants in conventional structures is improbable. At considerably greater distances the immediate effects will be weaker and damage to structures will be minor, e.g., broken windows and damage to window frames and doors. The radiation from fallout may be significant in this region, but this is a delayed effect which will be considered later (§12.48 *et seq.*). Between the zone of total destruction and the area at which damage is not significant, there is a region in which protective measures can determine whether inhabitants survive, with little or no injury, or whether they become serious casualties.

12.08 The distances from ground zero within which various degrees of destruction may be expected depend primarily upon the energy yield of the explosion and the conditions of the burst, i.e., air, surface, etc. The topography and weather also influence these distances. By using the data presented in the earlier chapters, it is possible to draw a series of circles, as depicted in Fig. 12.08, representing areas within which effects of different types are to be expected for air bursts of various yields from 10 kilotons to 10 megatons TNT equivalent. The height of burst is such as to maximize the distance to which each effect extends; in other words, the radii of the circles give the greatest ranges at which the indicated thermal radiation, initial nuclear radiation, and overpressure levels will occur for any air burst of the given energy yield. It should be mentioned that the circular areas depict an idealized situation. Actually, as was the case in Japan, the pattern would be distorted by the conditions of the terrain, weather, etc. Two or more weapons detonated within a short distance can, of course, change the situation considerably.

12.09 Within the ring at which the blast overpressure is 5 pounds per square inch (5 psi), nearly all conventional houses will be damaged beyond repair. Even strong buildings, such as reinforced concrete and steel structures, will suffer damage and, without protective measures, the casualties to the inhabitants of this area will be high. In the central zone of heavy damage, there will alsa be a great fire hazard. Individuals in this area will be exposed not only to the effects of blast, but also to nuclear and thermal radiation. Apart from fortuitous circumstances, few persons will survive who have not sought protection in strong structures or shelters which will withstand the fire, blast, and shock and which will attenuate the radiation.

12.10 At distances from the burst where the blast overpreseure is 1 psi, the destructive effect of the air blast wave is minor. Window frames, doors, and plaster will suffer light damage. Window panes will be broken at much greater distances. The initial nuclear radiation dose will be so small that its immediate consequences are negligible, but thermal radiation may still be a significant source of

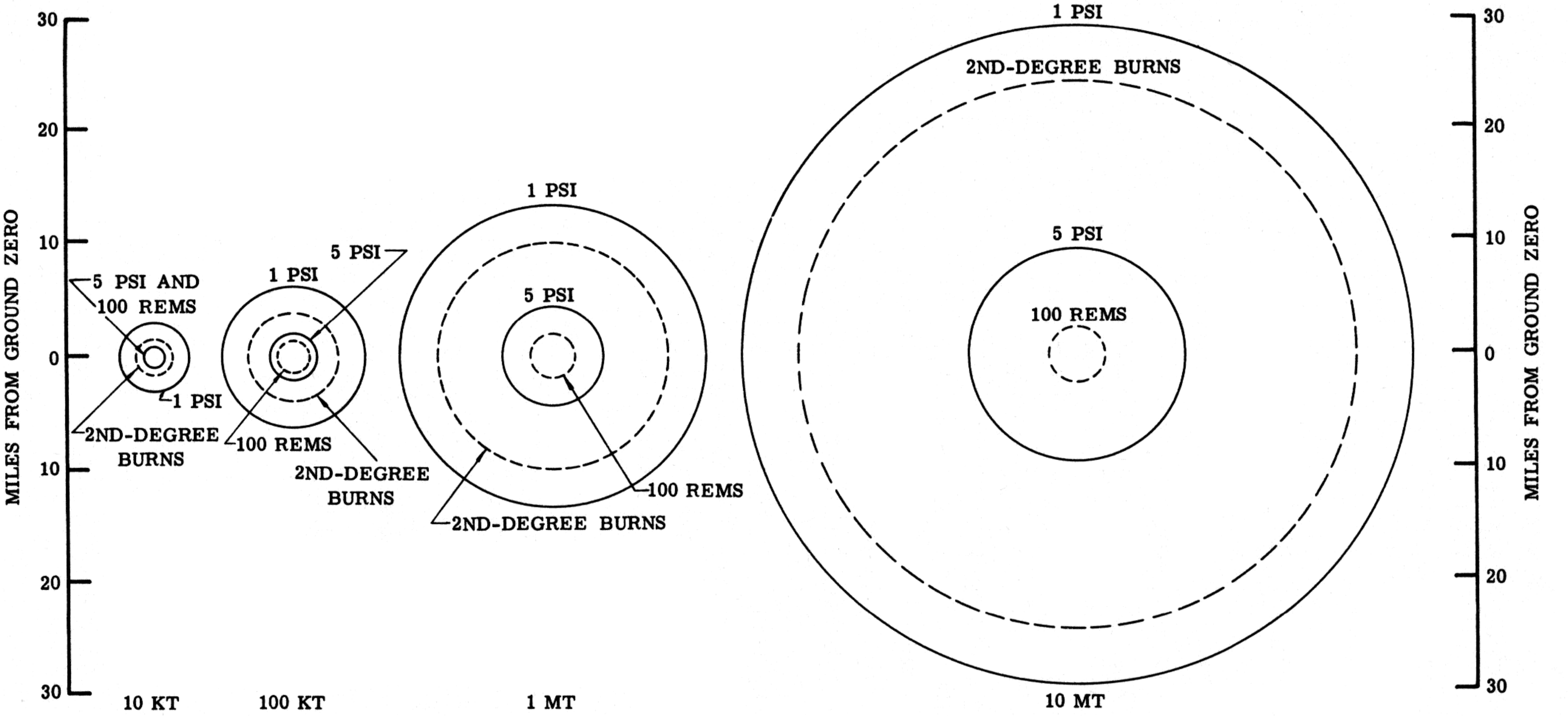


Figure 12.08. Idealized ranges for effects of air burst with the heights of burst optimized to give the maximum range for each individual effect.

casualties. Second-degree burns may be experienced at distances approaching those for 1 psi overpressure and less severe burns may be suffered at much greater distances from ground zero. Eye injury may also occur at even greater ranges and for high-altitude bursts of megaton weapons, this distance may be as much as several hundred miles. Furthermore, in dry, clear weather, many small fires would probably be ignited in newspapers and other thin combustible materials both within and outside of buildings.

Effective Protection Areas

12.11 In Japan, where little evasive action was taken, the survival probability depended upon whether the individual was outdoors or inside a building and, in the latter case, upon the type of structure. At distances between 0.3 and 0.4 mile (530 and 700 yards) from ground zero in Hiroshima the average survival rate, for at least 20 days after the nuclear explosion, was less than 20 percent. Yet in two reinforced-concrete office buildings, at these distances, almost 90 percent of the nearly 800 occupants survived more than 20 days, although some died later from radiation injury. Furthermore, of approximately 3,000 school students who were in the open and unshielded within a mile of ground zero at Hiroshima, about 90 percent were dead or missing after the explosion. But of nearly 5,000 students in the same zone who were shielded in one way or another, only 26 percent were fatalities. These facts bring out clearly the greatly improved chances of survival from a nuclear explosion that could result from the adoption of suitable warning and protective measures.

12.12 As a rough guide, the inner range at which protection in conventional structures could be achieved may be supposed to be that where the overpressure is 5 pounds per square inch and the outer range, beyond which casualties will be small *for an air burst*, is at 1 pound per square inch (or the limit for second-degree burns). As seen above, survival in Hiroshima was possible in buildings at such distances that the overpressure in the open was 15 to 20 pounds per square inch. The somewhat arbitrary choice of an overpressure of 5 pounds per square inch, which was experienced at a little over a mile from ground zero in Japan, is thus very conservative. In any case, it is evident from the circles in Fig. 12.08 that the area over which protection could be effective in saving lives is roughly eight to ten times as great as that in which the chances of survival are small. It may be concluded, therefore, that a considerable proportion of the population "at risk" from a nuclear explosion would be in an area in

12.17 The time sequence referred to in § 12.16 brings up another aspect of nuclear weapons effects that has a bearing on protection. Except very close to ground zero, even the immediate effects do not occur simultaneously. The first, almost instantaneous, indication of a nuclear explosion in the air or on the earth's surface is a brilliant flash of light. In many circumstances, it may be feasible, after observing the flash, to take some appropriate protective action that could greatly minimize the degree of injury suffered. At distances beyond those at which the immediate blast, thermal, and initial nuclear effects of the explosion are significant, there may be some time to make final preparations to decrease the early fallout.

12.18 As a general guide for planning purposes, it is useful to know the magnitudes of the respective immediate effects at a range of distances from an explosion of given yield. This information can be obtained from various figures and tables given in earlier chapters and can be identified from the list in the table of contents at the beginning of the book. A tabular summary of part of the data for air bursts, which may be more convenient for some purposes, is given in Table 12.18. The heights of burst are such as to maximize the various effects. An asterisk indicates that the particular distance is within the fireball; otherwise a blank space implies that the value is too small to be significant. The initial nuclear radiation doses are not given for distances of 5 miles or more for they are extremely small even for a 10-megaton explosion.

BLAST EFFECTS

EFFECTS ON STRUCTURES

12.19 Injury to individuals both inside and outside a structure may occur because of the blast damage to that structure. Persons in the interior of the building can be injured and trapped by collapse and fire, and those outside can be hurt by flying debris. For these and other reasons, an important aspect of protection is an understanding of the relative ability of different structures to withstand damage from air blast. Both the peak overpressure and the peak dynamic (or wind) pressure determine the amount of the damage, but for certain structures one or the other of these pressures has the dominant effect. For most office-type and residential buildings, including ordinary houses, the extent of destruction is mainly dependent on the peak overpressure, and an approximate correlation between the overpressure and the expected physical damage is given in Table 12.19.

Table 12.22a

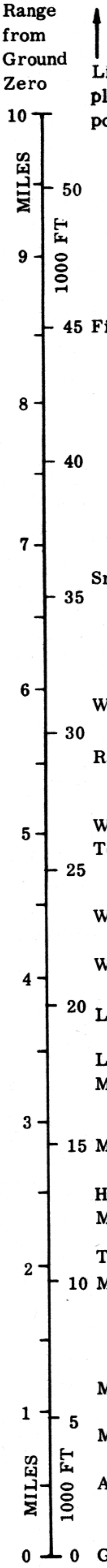
DAMAGE RANGES FOR 20-KT TYPICAL AIR BURST

Peak Wind Velocity (mph)	Positive Phase Duration (sec)	Peak Dynamic Pressure (psi)	Peak Over-Pressure (psi)	Range from Ground Zero		
				MILES	1000 FT	
				↑		Light damage to window frames and doors, moderate plaster damage out to about 4 miles; glass breakage possible out to 8 miles.
				2		
70	0.95	0.09	2.0		10	
				1.8		Fine kindling fuels: ignited.
79	0.94	0.12	2.3		9	Wood-frame buildings: moderate damage. Smoke stacks: slight damage.
				1.6		
93	0.92	0.17	2.7		8	
				1.4		
112	0.90	0.27	3.2		7	Wood-frame buildings: severe damage. Radio and TV transmitting towers: moderate damage. Wall-bearing, brick building (apartment house type): moderate damage.
				1.2		
139	0.86	0.42	4.2		6	
						Wall-bearing, brick buildings (apartment house type): severe damage.
				1.0		Telephone & power lines: limit of significant damage.
190	0.80	0.80	6.0		5	Multistory, wall-bearing buildings (monumental type): moderate damage. Light steel-frame, industrial buildings: moderate damage.
				0.8		
291	0.72	1.50	10.0		4	
						Multistory, wall-bearing buildings (monumental type): severe damage. Light steel-frame industrial buildings: severe damage. Highway and RR truss bridges: moderate damage.
				0.6		
431	0.63	3.90	16.3		3	
						Multistory, steel-frame building (office type): severe damage. Transportation vehicles: moderate damage. Multistory, blast-resistant designed, reinforced-concrete building: moderate damage.
				0.4		
459	0.54	7.50	22.5		2	Multistory, reinforced-concrete, frame building (office type): severe damage. Multistory, blast-resistant designed, reinforced-concrete buildings: severe damage. All other (above ground) structures: severely damaged or destroyed.
260	0.44	2.70	30.0	0.2	1	
				0	0	Ground zero for 20 KT air burst.

TABLE 12.22b

DAMAGE RANGES FOR 1-MT TYPICAL AIR BURST

Peak Wind Velocity (mph)	Positive Phase Duration (sec)	Peak Dynamic Pressure (psi)	Peak Over-Pressure (psi)
44	3.45	0.036	1.2
51	3.45	0.049	1.4
60	3.44	0.072	1.7
72	3.43	0.11	2.1
89	3.40	0.16	2.6
117	3.24	0.28	3.5
177	3.02	0.60	5.5
278	2.69	1.40	9.4
464	2.25	5.22	18.0
307	1.75	3.60	27.0



Light damage to window frames and doors, moderate plaster damage out to about 15 miles; glass breakage possible out to 30 miles.

Fine kindling fuels: ignited.

Smokestacks: slight damage.

Wood-frame buildings: moderate damage.

Radio and TV transmitting towers: moderate damage.

Wood-frame buildings: severe damage.
Telephone & power lines: limit of significant damage.

Wall-bearing, brick buildings (apartment house type): moderate damage.
Wall-bearing, brick buildings (apartment house type): severe damage.
Light steel-frame, industrial buildings: moderate damage.
Light steel-frame, industrial buildings: severe damage.
Multistory, wall-bearing buildings (monumental type): moderate damage.
Multistory, wall-bearing buildings (monumental type): severe damage.
Highway and RR truss bridges: moderate damage.
Multistory, steel-frame building (office type): severe damage.
Transportation vehicles: moderate damage.
Multistory, reinforced-concrete frame buildings (office type): severe damage.

Multistory, blast-resistant designed, reinforced-concrete buildings: moderate.
Multistory, blast-resistant designed, reinforced-concrete buildings: severe.
All other (above ground) structures: severely damaged or destroyed.

Ground zero for 1 MT air burst.

TABLE 12.29—ARRIVAL TIME FOR PEAK OVERPRESSURE

Distance (miles)	*Explosion yield*				
	1 KT	*10 KT*	*100 KT*	*1 MT*	*10 MT*
			(Time in seconds)		
1	4. 3	3. 6	3. 7	2. 5	1. 5
2	>9	8. 1	7. 4	6. 5	5. 0
3	--------	>13	12	11	9. 5
5	--------	--------	21	20	16
7	--------	--------	>30	28	26
10	--------	--------	--------	42	37
20	--------	--------	--------	>90	83
30	--------	--------	--------	--------	>130

12.30 It is seen that at 10 miles from a 10-megaton air burst, which is within the area where protection against blast could be effective, some 37 seconds would elapse before arrival of the blast wave. If prompt action is taken, a person in a building could reach a position of the type indicated above. In the open, some protection against the blast may be obtained by falling prone, and remaining in that position until the wave has passed. In the prone position, with the head directly toward or directly away from the explosion, the area of the body exposed to the onrushing blast wave is relatively small and the danger of displacement is thereby decreased (cf. § 11.38).

THERMAL RADIATION EFFECTS

EFFECTS ON PERSONNEL

12.31 The main direct effects of thermal radiation on human beings are skin burns, generally called flash burns to distinguish them from flame burns, and permanent or temporary eye damage. Burns are classified by "degree"; first-degree burns being mild in nature, roughly similar to moderate sunburn; they should heal without special treatment. Second-degree burns are associated with blister formation and if a significant area of the body is involved, medical attention is necessary (§ 11.44 *et seq.*). The approximate limiting distances from air bursts of various total yields at which first- and second-degree burns of exposed (light-colored) skin may be expected are given in Table 12.31. Third-degree burns, which involve the entire thickness of the skin, can occur at shorter ranges. For a surface burst, the respective distances are decreased to about four-fifths of the values in the table. The ranges shown are actually from the burst point rather than from ground zero, but at the heights of burst that maximize the distances over which burns are experienced, the differences are small.

TABLE 12.31

RANGES FROM GROUND ZERO FOR BURNS TO BARE SKIN FROM AIR BURSTS*

	Explosion yield				
	1 KT	*10 KT*	*100 KT*	*1 MT*	*10 MT*
	(Distance in miles)				
First-degree burn	0. 7	1. 9	5. 3	14	>30
Second-degree burn	0. 5	1. 5	4. 0	11	24

*For a surface burst the distances are about four-fifths those for an air burst of the same yield.

12.32 The data presented in Table 12.31 are applicable to reasonably clear atmospheric conditions. Fog or mist near the ground or a layer of cloud between the point of the explosion and the ground would attenuate the thermal radiation and thus decrease the ranges at which flash burns may be experienced by exposed persons. However, snow on the ground or cloud layers above the explosion provide reflecting surfaces which increase these ranges.

12.33 Eye injuries are of two main types: temporary (flash blindness) and permanent (chorioretinal burns), as described in § 11.69 *et seq.* Both kinds of injury can occur at great distances from the explosion, considerably greater even than those for first-degree burns given in Table 12.31. The nature and extent of the eye injury depends on the yield and type of burst, on the orientation of the observer to the burst, on the clarity of the atmosphere, and on the size of the pupil opening. As a general rule, permanent eye injury would be expected only in those persons who were looking directly at the fireball. Flash blindness, on the other hand, could be quite general over a large area.

PROTECTIVE MEASURES

12.34 In an air or surface burst, the thermal radiation is received in two pulses, in each of which there is a maximum of intensity followed by a decrease. If an individual is caught in the open or is near a window in a building at the time of a nuclear explosion, evasive action to minimize flash burn injury should be taken, if possible, before the maximum in the second pulse. At this time only 20 percent of the thermal energy will have been received, so that a large proportion can be avoided if shelter is obtained before or soon after the second thermal maximum. The elapsed times between the instant of the explosion and the second thermal maximum for air and surface bursts of various energy yields are recorded in Table 12.34. From this table it is seen that the prospects of being able to take evasive action are not good for air or surface bursts of low energy yield, but some possibility may exist for explosions in the megaton range.

TABLE 12.34

TIME TO SECOND THERMAL MAXIMUM

	Explosion yield				
	1 KT	*10 KT*	*100 KT*	*1 MT*	*10 MT*
Time (seconds)	0. 03	0. 1	0. 3	1. 0	3. 2

12.35. The major part of the thermal radiation travels in straight lines, and so any opaque object interposed between the fireball and the exposed skin will give some protection. This is true even if the object is subsequently destroyed by the blast, since the main thermal radiation pulse is over before the arrival of the blast wave.

12.36 At the first indication of a nuclear explosion, by a sudden increase in the general illumination, a person inside a building should immediately fall prone, as described in § 12.30, and, if possible, crawl behind or beneath a table or desk or to a planned vantage point. Even if this action is not taken soon enough to reduce the thermal radiation exposure greatly, it will minimize the displacement effect of the blast wave and provide a partial shield against splintered glass and other flying debris. An individual caught in the open should fall prone to the ground in the same way, while making an effort to shade exposed parts of the body. Getting behind a tree, building, fence, ditch, bank, or any structure which prevents a direct line of sight between the person and the fireball, if possible, will give a major degree of protection. If no substantial object is at hand, the clothed parts of the body should be used to shield parts which are exposed. There will still be some hazard from scattered thermal radiation, especially from high-yield weapons at long range, but the decrease in the direct radiation will be substantial.

12.37 Clothing of the proper kind provides good protection against flash burns. Materials of light color are usually preferable to dark materials because the former reflect the radiation. Clothing of dark shades absorbs the thermal radiation and may become hot enough to ignite, so that severe flame burns, which are more serious that the flash burns, may result. Woolen materials give better protection than those of cotton of the same color, and the heavier the fabric the greater the protection. An air space between two layers of clothing is very effective in reducing the danger of flash burns.

12.38 Protection against eye injury is difficult, especially for those persons who happen to be facing the burst point. The blink reflex, i.e., the automatic blinking of the eye, which requires 0.15 second, may be helpful in providing some protection from air and surface bursts in the megaton range. It is doubtful, however, if much can be done at those distances where the same total amount of thermal energy is received from weapons of lower energy. In a nuclear explosion at high altitude, that is, at heights above 20 miles, the thermal radiation is emitted in a single rapid pulse. Assuming the total thermal energy received by a person at a particular location is sufficient to cause flash burns or eye injury, it seems improbable that any evasive action will be effective, as even the involuntary blink will not be in time to help very much. Ordinary sunglasses will provide little or no protection against eye damage, since much more opaque material would be required to decrease the radiation intensity. In all cases individuals should make every effort to avoid looking toward the fireball.

FIRE PROTECTION

12.39 After a nuclear attack on an urban area, extensive fires may develop as they did in Japan. Such fires were started both directly by thermal radiation and by secondary blast effects, i.e., overturning of stoves, short circuiting of electrical wires, etc. (§ 7.69). Appropriate fire control action may be directed along three lines, namely, (1) reduction of potential ignition points, (2) provision for isolation or rapid extinction of ignitions to prevent formation of large fires, and (3) minimization of the consequences should large-scale fires develop.

12.40 Since the elimination of wood as a construction material for houses is virtually impossible, potential ignition points can be decreased by continuous upkeep of existing wood structures and by taking steps to keep yards free from all combustible trash. As stated in § 7.57 *et seq.*, it was clearly demonstrated at the 1953 tests in Nevada that a well-maintained house, with a yard free from trash, is much more capable of withstanding the thermal effects of a nuclear explosion than is a poorly-maintained house or one with an unkept yard. Fire-resistive furnishings, e.g., draperies, rugs, etc., made of vinyl plastic or wool, also proved to be advantageous in these tests.

12.41 The second aspect of fire control action is to plan and train for the elimination of small fires before they can grow into serious ones.

In Japan the fires were so numerous and spread so rapidly that it would have been beyond the capability of regular fire departments to deal with them even if the latter had survived the bombings. The training of private individuals in emergency methods of firefighting, such as were developed in Europe during World War II, is therefore desirable. By extinguishing small fires soon enough, the number of serious fires may be sufficiently small to be dealt with by professional firefighters.

12.42 Conventional methods for preventing the spread of large fires, by the use of natural and artificial fire breaks, were not too successful in Japan, for the reasons mentioned in § 7.72. Nevertheless, consideration should be given to the provision of adequate fire breaks and to the zoning and planning of urban areas. As seen in § 7.55, the potential for the development and spread of fires is greatest in wholesale distribution and slum residential areas. Dispersal and protection of utilities and emergency services should be included in such planning.

INITIAL NUCLEAR RADIATION

Effects on Personnel

12.43 The initial nuclear radiation consists of gamma rays and neutrons received during the first minute after the explosion. Doses of this radiation up to 100 rems, over the whole body, would have little or no immediate observable effects on exposed individuals. The only effect expected might be a slight feeling of fatigue in some people. Many persons receiving larger doses, up to 200 rems, would not be greatly affected by the radiation, except for blood changes. For the present purpose, however, it will be supposed that a whole-body dose of 100 rems will cause few, if any, casualties requiring medical attention. At the other extreme, it is probable that every person receiving 1,000 rems over the whole body will become sick within 4 hours (or less) of exposure and will die in 2 or 3 weeks. Between these extremes there is a great deal of variation in the expected effects on personnel, but at an exposure of around 400 to 500 rems, all will be nauseated and vomit on the first day, and most will require medical care. However at this exposure, at least one-half of the people will probably recover.

12.44 The actual distances from air bursts of various yields at which the initial nuclear radiation will produce doses of 100, 500, and 1,000 rems, respectively, to completely unprotected individuals are shown in Table 12.44. However, the heights of burst which maximize these distances are such that the latter are not very different from the ground zero ranges. For purposes of comparison, the distances for an overpressure of 5 pounds per square inch and for second-degree flash burns of exposed skin are included. It is seen that the hazards from blast and thermal radiation extend to much greater distances than do those from initial nuclear radiation, especially for weapons of yields in excess of 10 kilotons. For example, an individual 2 miles from a 1-megaton burst probably would show no significant symptoms of nuclear radiation sickness, but the thermal radiation exposure would be 210 calories per square centimeter (see Table 12.18). Less than 7 calories per square centimeter are sufficient to produce a second-degree skin burn from an explosion of 1 megaton. The corresponding blast wave overpressure of 18 pounds per square inch would cause severe damage to the strongest conventional structures (cf. Table 12.19).

TABLE 12.44

RANGES FROM GROUND ZERO FOR VARIOUS INITIAL NUCLEAR RADIATION DOSES FROM AIR BURSTS*

	Explosion yield				
	1 KT	*10 KT*	*100 KT*	*1 MT*	*10 MT*
	(Distances in miles)				
Radiation Dose					
100 rems	0. 7	1. 0	1. 3	1. 8	2. 4
500 rems	0. 6	0. 8	1. 1	1. 5	2. 1
1,000 rems	0. 5	0. 7	1. 0	1. 4	2. 0
Other Effects					
5 psi	0. 4	0. 9	2. 0	4. 3	9. 2
Second-degree burns	0. 5	1. 5	4. 0	11	22

*The distances for a specified radiation dose are slightly less for a surface burst.

PROTECTION FROM INITIAL NUCLEAR RADIATION

12.45 It is apparent that for weapons with yields greater than 10 kilotons, the regions in which large doses of initial nuclear radiation could be received are those of high blast pressure and intense thermal radiation. Protection against all three effects would be provided by a massive reinforced, fire-resistant building. An 18-inch thickness of concrete, for example, would reduce the fatal dose of 1,000 rems to the tolerable one of about 100 rems. Thus, aboveground buildings of massive construction would provide some protection against the initial nuclear radiation. Additional protection may be obtained in basements beneath substantial concrete floor slabs. The surrounding earth also helps in this connection; a 26-inch thickness of earth attenuates the radiation by a factor of about ten and 3 feet by about thirty.

12.46 The immediate evasive action suggested earlier for limiting the effects of thermal radiation and blast to a person in the open may assist, to a lesser extent, in reducing the dose of initial nuclear radiation. From high-yield weapons, in particular, a second or two elapses before much of the nuclear radiation is delivered at distances where survival is possible (§ 8.43). Table 12.46 gives the percentage of the total initial gamma-radiation dose received at given distances from 20-kiloton and 5-megaton explosions as a function of time. The total unshielded dose would be about 4,500 roentgens in each case.

TABLE 12.46

INITIAL GAMMA-RADIATION DOSE AS A FUNCTION OF TIME

		Time (seconds)						
	Distance	*1*	*2*	*4*	*7*	*10*	*15*	*20*
Explosion yield	*(miles)*	*Percentage of initial gamma-radiation dose delivered*						
20 KT	0. 5	67	78	88	95	97	100	-----
5 MT	1. 5	5	17	43	76	90	98	100

12.47 As shown by the table, there is some possibility of reducing the radiation dose by immediate evasive action. However, from the numbers given above for the attenuation by concrete and earth, it is obvious that a nuclear radiation shield must be very massive if it is to be effective. Normal clothing, for example, will do little to attenuate initial nuclear radiation, although it may provide complete protection from thermal radiation. Another difficulty in connection with obtaining shelter in the open is the scattering of nuclear radiation, so that it may reach a person from many directions and not just along a direct line from the point of explosion.

RESIDUAL NUCLEAR RADIATION

FALLOUT HAZARD

12.48 The principal effects on personnel from residual radiation are similar to those from comparable doses of initial nuclear radiation as described in the preceding section. However, the hazards of exposure to residual radiation are entirely different from exposure to initial radiation and these hazards are described in this section.

12.49 Protection against residual nuclear radiation occupies a position of special significance. Because the early fallout can cover an area much larger than that over which blast, thermal radiation, and initial nuclear radiation are significant, it is possible for people to become casualties at such distances from the explosion that the immediate effects are negligible or completely absent. As noted earlier, it is not feasible to state the degree of hazard from residual radiation in a reasonably accurate manner because it is so highly dependent upon conditions, especially wind speeds and directions over a considerable height. It is certain, however, that a surface burst in the megaton range will lead to contamination of very large areas by early fallout. This fallout will reach the ground very soon after the explosion at near distances, but at distances of several hundred miles, up to 24 hours may elapse before the fallout starts to arrive.

12.50 The early fallout hazard is of two main kinds: one results from the actual contact of the radioactive material with the skin, causing what are called "beta burns" produced by the action of the beta particles, and the second is due to the continuous exposure of the body to gamma rays, both direct and scattered, from fallout particles. It is with the second of these hazards that the discussion here will be mainly concerned. The protective measures for use against beta burns are chiefly associated with keeping the dust-like particles off the skin. If the fallout dust does get on the skin, it should be immediately washed off with soap and water. The possible hazard from entry of radioactive material into the body by ingestion will be considered later (§ 12.66 *et seq.*).

INDUCED RADIOACTIVITY

12.51 In addition to the radioactive fallout, there may be a residual radiation hazard near ground zero caused by induced activity resulting from the capture of neutrons by various elements in the soil, especially sodium and manganese. The induced-activity hazard may exist on the ground after an air burst when the initial fallout is virtually absent. However, this activity not only decays much more rapidly than does that from fallout, but it extends only a short distance (1 mile or less) from ground zero. Since the destruction in this area would be considerable, the only persons entering it for some time after the explosion should be rescue teams and others performing urgent missions. Such teams would be equipped with instruments to inform them of the radiation hazard.

PROTECTIVE MEASURES

12.52 Assuming the population is to remain in the fallout area, and not be evacuated, it is necessary to obtain protection which attenuates the gamma radiation. The basic principle to be borne in mind is that any massive or thick material will decrease the nuclear radiation level to some extent, whereas lighter construction, e.g., window areas, hollow, thin, or light walls, etc., permits the radiation to penetrate. A layer of concrete 8 inches thick or of earth 12 inches thick will yield an attenuation factor of 10; [2] doubling these thicknesses will increase the factor to 100. Thus, each extra foot of earth between an individual and the fallout will increase the protection factor tenfold. It should be remembered that scattered radiation will come from many directions, and so protection is necessary from all directions, either by the use of a mass of material or by distance.

12.53 Information has been published that describes procedures and standards for evaluating the potential of existing structures as fallout shelters and for modifying such structures to improve their effectiveness in this respect. The recommended procedures and standards may also be utilized in the design of new structures. Furthermore, instructions for building simple and effective fallout shelters are readily available. Basically, a fallout shelter is a structure with massive walls and ceiling. Practical materials of construction are earth, concrete, or solid masonry. Attenuation of the gamma radiation is provided by absorption in these materials and by the distance separating the fallout particles from the people in the shelter.

12.54 Since a shelter may have to be occupied continuously for periods as long as 2 weeks, until the natural decay of the radioactivity outside will allow the people to emerge, stocks of food and other supplies will be required. Where fallout arrives soon after the explosion, the early radiation dose rate will be high. It may then be necessary to wait several days before it is possible to come out of the shelter for more than a limited period without risking a radiation dose of sufficient magnitude to cause serious illness. In the path of the fallout, the early radiation levels will be lower at more distant points from the explosion, and the time necessary to occupy the shelter will be shorter, unless "hot spots" are present (§ 9.55). However, in any area where contamination is at all significant, it will probably be necessary to spend the first day or two after the burst sheltered from the residual gamma radiation. It is during the period immediately following the nuclear explosion, when the radiation level is at its highest, that protection is most important.

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[2] It should be noted that more than twice these thicknesses of concrete (18 inches) and of earth (26 inches) are required to attenuate the initial nuclear radiation to the same extent (§ 12.45) because the energy of the initial gamma rays is greater than in the residual (fallout) radiation.

12.55 A fallout shelter of the kind referred to in §12.53 will provide a protection factor of about 200 from the residual radioactivity; in other words, the dose rate in the shelter will be only ½ percent of that measured outside at a height of 3 feet above the ground. Where a shelter is not available, a similar protection factor from radiation can be obtained in the following manner in a small area of the basement of a two-story house. A sturdy table is placed in a corner adjacent to an unexposed outer wall and covered with 10 to 12 inches of soil, sandbags, solid concrete block, etc., according to what is available. If there are no heavy partitions or walls near the corner of the basement chosen, a layer of sandbags or concrete blocks should be stacked along the walls up to the height of the material on top of the table. Within the area under the table, there will be a protective factor of at least 100 from fallout radiation. The disadvantage of this type of protection is that it is unlikely that stocks of food and water would be available within the shelter, so that it could not be occupied continuously for an extended period, as could the more permanent type outlined previously. In almost any house with a buried basement, having uniformly thick exterior walls, a protection factor of 20 to 40 is possible. The maximum protection can be obtained near the floor and in the corners of the basement adjacent to an unexposed outer wall.

12.56 Before leaving a shelter, either temporarily or permanently, it is highly desirable that the radiation dose rate, both in the immediate area of the shelter and in the surrounding vicinity, be known. Marked variations in fallout patterns have been observed in weapons tests, with unexpected areas (hot spots) of exceptionally high activity. Hence, it is not sufficient to know merely that a nearby location is relatively safe. Communications equipment, e.g., battery-powered radios, and radiation measuring instruments should be in shelters. Otherwise it will not be possible to obtain information on radiation dose rates in the locality and in the immediate vicinity of the shelter, particularly at early times when high radiation levels will prevent radiation monitors from moving safely and freely about the community. As a rough rule-of-thumb, it may be stated that for every sevenfold increase in time, the radiation level will decrease by a factor of 10, provided the fallout is complete. For example, the radiation level at the end of 7 days will have fallen to roughly one-tenth of that at the end of 1 day. At the end of 49 days, it will have decreased by a factor of 100, etc.[3]

12.57 It is appropriate to mention here that whether or not fallout is visible to the eye, its measurement requires the use of suitable

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[3] The rule is applicable to any unit of time; thus at 7 hours the residual radiation level will be one-tenth of that at 1 hour, at 14 hours it will be one-tenth of that at 2 hours, and so on, provided the fallout is complete at both times.

instruments sensitive to nuclear radiations. Some, although perhaps not all, of the fallout in the Marshall Islands, after the test explosion of March 1, 1954 (§ 9.100 *et seq.*), could be seen as a white powder or dust. This was due, partly at least, to the light color of the calcium oxide or carbonate of which the particles were mainly composed. It is probable that whenever there is sufficient fallout to constitute a hazard, the dust will be visible. Nevertheless, continuous monitoring with instruments for radioactive contamination would appear to be essential in all areas in the vicinity of the burst.

RADIOLOGICAL SURVEYS

12.58 As soon after a nuclear explosion as conditions permit, radiological monitoring surveys will have to be initiated for the purpose of developing information on the extent and levels of the contamination. At early times in heavily contaminated areas, where dose rates will be very high, only the most limited amount of monitoring can be accomplished by individuals with hand-carried instruments. In these circumstances, some kind of remote radiation monitoring equipment may be necessary. This will permit the monitor to remain within the shelter while taking readings of the dose rate outside.

12.59 The most rapid method for obtaining radiation levels in a large area is by aerial survey. Because of their long range in air, gamma rays can be detected by sensitive instruments at a height of a few thousand feet. Low-flying airplanes or helicopters, carrying suitable radiation instruments for measuring dose rates, can survey large areas unimpeded by damage on the surface and by impassable streets and roads. Moreover, by making initial flights at an altitude of 1,600 feet or so, the dose rates are only about 1 percent of those on the ground, so that the hazard to the monitor is decreased accordingly.

12.60 The dose rates measured at an altitude must be multipled by an appropriate factor to give the approximate dose rates near the ground. This factor will depend primarily on the height above the ground and nature of the terrain. In the absence of more specific information, the data in Fig. 9.181 may be used to estimate the attenuation factor at a known altitude with reference to that at a height 3 feet above the ground.

12.61 The aerial survey is important because it can be made readily and can provide information which might be impossible to obtain in any other way at the time of interest. Nevertheless, such a survey can serve only as a rough guide and should be made only after all the early fallout is out of the air and on the ground. For points of special

The allowable dose (*D*) is divided by the dose rate (*R*) at the time of entry to give D/R, i.e., 25/45=0.55. This result falls between two values in the left-hand column of Table 12.64, and the smaller one is taken. Follow the $D/R=0.5$ line horizontally until the column headed "8 hours" after the detonation is reached. The allowable stay time is seen to be 31 minutes; for $D/R=0.6$, the corresponding time is 38 minutes, and so the actual permissible stay time would be about 34 minutes. By using both Tables 12.63 and 12.64, a variety of other estimates can be made.

12.65 There are two important reservations which must be kept in mind in using Tables 12.63 and 12.64. First, if there is any change in the situation, either by further contamination or by decontamination in the period between the two times concerned, the results will not be valid. Second, even if the conditions under which the tables are applicable are fulfilled, the estimates should be used for *planning purposes only*, and to provide a guide for any action that may be required. Changes in dose rates and total accumulated doses over a period of time must always be checked by instruments.

FOOD AND WATER

12.66 After a nuclear attack, in addition to protection from external residual radiation exposure, it is important that personnel in the fallout area also be protected from internal radiation exposure due to ingestion of radioactive fallout material along with food and water. Food and water are not adversely affected by exposure to the residual radioactivity. The principle of protection to be understood is that fallout material must be removed from food and water prior to consumption to prevent this material from getting inside the body. Relative to that which could be taken into the body by eating and drinking, it appears that the amount of radioactive material taken in by inhalation may be small (see §11.160). Nevertheless, air which contains fallout particles should not be directly inhaled without a protective respiratory device (such as a dust-filter respirator) until it is established by monitoring procedures that the air is free from radioactive contamination.

12.67 The contamination of emergency food and water supplies by residual radiation can be prevented by storing them in dust-tight containers. Although the outside of a container may become contaminated by fallout, most of the radioactive substance can be removed by washing the container before it is opened. The foods or fluids can then be removed and consumed without significant contamination.

12.68 If emergency food supplies do become contaminated, or if it is necessary to resort to contaminated sources after emergency supplies are exhausted, many types of food can be treated to remove the radioactive material. Fresh fruits and vegetables can be washed or peeled to remove the outer skin or leaves. Food products of the absorbent type cannot be decontaminated in this manner and should be disposed of by burial. Boiling or cooking of the food has no effect in removing the fallout material. Milk, from cows which survive in a heavily contaminated area, may not be safe to drink because of the radioiodine content and this condition may persist for weeks or months.

12.69 Domestic water supplies from underground sources will usually remain free from radioactive contamination. Water supplies from surface sources may become contaminated if watersheds and open reservoirs are in areas of heavy fallout. However, most of the radioactive fallout material would be removed by regular water treatment which includes coagulation, sedimentation, and filtration. If a surface water supply is not treated in this manner, but merely chlorinated, it may be unfit for consumption for several days after an attack. As a result of dilution and natural decay the contamination will decrease with time.

12.70 If the regular water supply is not usually subjected to any treatment other than chlorination, and an alternative source is not available, consideration should be given in advance planning to the provision of ion-exchange columns or beds for emergency decontamination use. Home water softeners might serve the same purpose on a small scale. The water contained in a residential hot-water heater would serve as an emergency supply, provided it can be removed without admitting contaminated water. Water may also be distilled to make it safe for drinking purposes. *It should be emphasized that mere boiling of water contaminated with fallout is of absolutely no value in removal of the radioactivity.*

DECONTAMINATION

12.71 Decontamination is the process of removing radioactive material from a location where it is a hazard to one in which it can do little or no harm. It is one of the means which are available for reducing the radiation dose that would be received from fallout. Preferably it should be accomplished under the supervision of personnel trained in decontamination procedures. Radiation measuring instruments should be used not only to determine the effectiveness of the decontamination but also to make sure that the contaminated material is disposed of in a safe manner.

12.72 Because of its particulate nature, fallout will tend to collect on horizontal surfaces, e.g., roofs, streets, tops of vehicles, and the ground. In the preliminary decontamination, therefore, the main effort should be directed toward cleaning such surfaces. The simplest way of achieving this is by water washing, if an adequate supply of water is available. The addition of a commercial wetting agent (detergent) will make the washing more efficient. The radioactive material is thus tranferred to storm sewers where it is less of a hazard. Covering the ground around a building with uncontaminated earth or removing the top layer of the ground to a distance, by means of earth-moving equipment, are methods for reducing the dose rate inside a building. Inasmuch as decontamination of streets, buildings, and other large items requires substantial manpower and resources, the effectiveness of these operations will benefit from sound planning and skilled supervision.

12.73 It is important to note, in connection with removal of contaminated earth for the purpose described above or to provide a means of transit, that the gamma rays from fission products can travel considerable distances through air. For example, at 3 feet above the ground, roughly 50 percent of the dose rate received in the center of a large, flat, uniformly contaminated area comes from distances greater than 50 feet away, and about 25 percent from distances more than 200 feet away. Thus, complete removal of the contaminated surface from a circle 200 feet in radius would reduce the dose rate in the center to about one-fourth of its original value. However, if the contaminated earth were not completely removed, but just pushed to the outside of the circle, the dose rate would be considerably greater than one-fourth the initial value.

12.74 It is apparent, therefore, that if facilities are to be provided across open country which is contaminated over a large area, bulldozing the top few inches of contaminated soil to the sides will be satisfactory only if a wide strip is cleared. Thus, if the strip is 250 feet in width, the radiation dose rate in the middle will be reduced to one-tenth of the value before clearing. A similar result may be achieved by scraping off the top layer of soil and burying it under fresh soil. Something like a foot of earth cover would be required to decrease the dose rate by a factor of ten.

12.75 Badly contaminated clothing, as well as rugs, curtains, and upholstered furniture, would have to be discarded and buried or stored in an isolated location. When the radioactivity has decayed to a sufficient extent, or if the initial contamination is not too serious, laundering may be effective in reducing the activity of clothing and fabrics, to permit their recovery. Thorough vacuum cleaning of furniture might be adequate in some cases, but an instrument check would be necessary before further use.

SUMMARY

PLANNING PROTECTION

12.76 In planning protection against the hazards associated with a nuclear attack, it must be recognized that the amount of protection that will be available to individuals is, in a large degree, directly related to the extent of public knowledge concerning nuclear weapons effects and associated protective measures, and to the steps taken prior to the attack to put these measures into a state of readiness. There are certain actions which can be taken by the unprepared in extreme emergencies, but the protection achieved is minor when compared to that which would be available to those who had made adequate preparations. Moreover, following an attack there are certain procedures that can tend to minimize the remaining hazards and these also will be made more effective by sufficient concern beforehand as to their implementation.

12.77 A massive, reinforced, fireproof shelter structure is required at close distances to protect individuals against the severe immediate effects (blast, thermal, and initial nuclear radiation) of a nuclear explosion. This type of protection is the most comprehensive and requires the greatest amount of preplanning effort and knowledge of the effects hazards. Conventional buildings may also be designed to be blast and fire resistant. Measures to minimize the thermal and fire hazard (§ 12.39 *et seq.*) may also be effected. In those areas where early fallout is expected to be a hazard, shelters may be constructed and provision made for occupying them for considerable lengths of time. Knowledge of warning systems and evacuation procedures will also minimize confusion. Moreover, possession of battery operated communications systems and of radiation monitoring equipment will make it possible to obtain information on the condition of the occupied area following an attack.

12.78 In the event that shelters are not available, certain evasive actions may prove helpful at distances where the immediate effects are least severe. By instantly falling prone and covering exposed portions of the body or getting behind opaque objects, much of the thermal radiation may be avoided, especially in the case of large-yield weapons. Under no circumstances should an individual look in the direction of the fireball. Staying behind thick walls or lying in a deep ditch may help to avoid initial nuclear radiation. All of the above actions will also help to decrease the possible danger from the blast wave. Moreover, persons should avoid areas which have frangible materials, such as window glass, plaster, etc., which may become flying debris by the action of the blast.

12.79 After the immediate effects of the nuclear explosion are over, certain acts are required to minimize the hazards of the early fallout and from the fires which may result from thermal radiation and secondary blast effects. First, if small fires can be quickly extinguished, extensive conflagrations may be prevented. This must be accomplished before the arrival of the fallout or in areas of low radioactivity levels. Some protection from the fallout may be secured in the basements of buildings or in a quickly constructed shelter, such as is described in § 12.55. It is important to keep from coming into physical contact with the fallout particles, and to prevent contamination of food and water sources. Monitoring equipment should be used to determine areas which have safe radiation levels and decontamination efforts can proceed to recover necessary equipment, buildings, and areas.

CONCLUSION

12.80 Much of the discussion presented in earlier sections of this chapter have been based, for simplicity, on the effects of a single weapon. It must not be overlooked that in a nuclear attack some areas may be subjected to several bursts. The basic principles of protection would remain unchanged, but protective action against *all* the effects of a nuclear explosion—blast, thermal radiation, initial nuclear radiation, and fallout—would become even more important. There is a good possibility that many people would survive a nuclear attack and this possibility would be greatly enhanced by utilizing the principles of protection in preattack preparations and planning, in taking evasive action at the time of an attack, and in determining what should be done in the recovery phase after the attack.