U.S. Joint Crossroads Committee

RADIOLOGICAL DEFENSE

Safety Manuals.

Vol. II

The Principles of Military Defense against Atomic Weapons

Armed Forces Special Weapons Project

November 1951

Chapter 1

HISTORICAL EXPERIENCE

THE ATOMIC BOMB IN WARFARE

The Hiroshima Bomb

1.01. The first use of the atomic bomb in warfare occurred on 6 August 1945, at Hiroshima, in Japan. This port city, which at the time had an estimated population of over 300,000 persons, military and civilian, lies on a flat, fan-shaped delta of the Ota River. Soon after 0800 on the aforementioned day, three United States aircraft appeared over the city, but little attention was paid to them. Half an hour before, the "all clear" had been sounded from an earlier warning and, consequently, all but a few persons had left the air-raid shelters and were on their way to work. It is estimated that some three-quarters of the population were then in the congested 4-square-mile center of the city, many of them still in the streets.

1.02. The bomb was dropped over the center of Hiroshima and exploded at a height of about 2,000 feet above the ground. This altitude was chosen deliberately, as will be seen later, in order to produce the maximum amount of damage to structures in the city. The explosion was accompanied by a brilliant flash of light and an intense wave of heat, that was felt nearly 4 miles away. Immediately thereafter came a violent blast of air the force of which destroyed, or rendered useless, buildings up to a distance of nearly 2 miles from the center of the explosion (figs. 1.02 a and b). As far away as 8 miles, glass was broken and plaster damaged. At the same time all public utilities—water, electricity, gas, transportation, and telephone services—were disrupted.

1.03 Due to the breaking of gas lines, the overturning of stoves and furnaces, and for other reasons, fires soon broke out in various parts of the city. Buildings damaged by the blast were particularly vulnerable to the spread of fire, and within 20 minutes of the detonation of the atomic bomb more than 4 square miles of Hiroshima were a mass of flames. However, little or nothing could have been done to restrict the conflagration. It is true that the fire-fighting services and equipment in Hiroshima were poor by American standards, but it is very doubtful if much could have been achieved, in the circumstances, by more efficient fire departments. Nearly 70 percent of the city's fire-fighting equipment was destroyed and about 80 percent of the firemen on duty were immediate casualties. Even if the men and machines had survived the blast, many places were inaccessible because of the streets being blocked with debris. Further, the damage to water pipes made the water pressure so low that it would have been of little use for controlling fires.

1.04. The atomic explosion over Hiroshima resulted in the death of about 70,000 persons and the injury of an almost equal number. Thus, nearly half of the city's population became immediate casualties. Many people became sick in subsequent weeks due to overexposure to the nuclear radiation that is a characteristic of the atomic bomb. The high casualty rate in Hiroshima was undoubtedly due to the fact, mentioned above, that at the time of the explosion a considerable proportion of the population was concentrated near the center of the city, with an unusually large number in the streets.

1.05. The three planes, which appeared over the city so soon after an "all clear" had been given, were not taken seriously. It was thought that they were observation planes, and even if they had been bombers, their bomb load was evidently not considered sufficient to merit a further disruption of the city's daily routine. From the standpoint of defense against the atomic bomb, the important lesson is that no enemy plane, whether it comes singly or in a group, can be disregarded. Had the inhabitants of Hiroshima remained in their shelters, the number of casualties would have been greatly decreased. The material destruction would presumably have been the same, but care of the injured and

Figure 1.02a. The Hiroshima Prefecture (approximately 1,000 yards from ground zero) before the atomic explosion.

rehabilitation and repair of the city after the explosion would have been greatly facilitated.

The Nagasaki Bomb

1.06. Three days after the attack on Hiroshima, at 1102 on 9 August 1945, an atomic bomb was exploded over the industrial seaport of Nagasaki, with a population of 230,000. The city lies on a small plain which extends up two relatively narrow valleys, between hills rising some 1,000 feet above sea level. The heavily industrialized part was located in the larger of the two valleys, and it was approximately 2,000 feet above this area that the bomb was exploded (fig. 1.06). As a result, the huge Mitsubishi Ordnance Plants, which were in the Arakami valley, were destroyed, but the harbor and commercial areas, and much of the residential area, escaped serious damage. One of the factors responsible was the hilly nature of the terrain. Many houses, built in ravines, were sheltered by the hills, and thus protected from the blast.

1.07. The fires which followed the blast spread more slowly and covered a smaller area (about 1.8 square miles) than at Hiroshima. There were two reasons for this. First, the factory area at Nagasaki, over which the bomb was dropped, contained less combustible material than the business and residential parts of Hiroshima. And second, the wind, which developed some time after the conflagration had become well established, tended to carry the fire up the valley in a direction where there was nothing to burn. Had the wind been in the opposite direction, toward the shore instead of away from it, the consequences might have been quite different.

1.08. Because of the tremendous psychological shock and the disruption of communications following the bombing of Hiroshima, reliable news was not available in other parts of Japan. Consequently, Nagasaki was little better prepared for the atomic attack, with the result that about 36,000 people were killed and 40,000 injured. The city had been on a warning alert for more than 2 hours before the bomb fell, but no raid alarm had been given and only a few hundred persons were in shelters. However, because of the time of day, and the different circumstances, the proportion of the population in the streets in Nagasaki was not so large as at Hiroshima. This may account, in part, for the smaller number of casualties.

Figure 1.02b. The Hiroshima Prefecture after the atomic explosion.

1.09. Since a large number of the inhabitants as well as considerable residential areas of the city survived the explosion, rescue efforts at Nagasaki were soon organized. The water supply was partially restored by the second day after the dropping of the bomb, and some electric power was available at the end of the same day. On the following day a few streetcars and railway trains were running again.

Studies of Damage and Casualties

1.10. The damage and casualties due to the atomic bombs at Hiroshima and Nagasaki are summarized in table 1.10. For purposes of comparison the corresponding figures are given for the destructive air raid on Tokyo on 10 March 1945, made largely with incendiary bombs, and the average of 93 air attacks on Japanese cities with similar weapons. The outstanding feature of the atomic bomb is seen to be the high casualty rate per square mile destroyed. Thus, atomic bombs have a greater "saturation" character than bombs of the more conventional type.

1.11. Soon after the cessation of World War II, teams of observers from the United States and from Great Britain went to Japan to make detailed studies of the effects of the atomic bombings on both structures and personnel. The main purpose of the studies was to obtain information useful in the development of defense measures. Comprehensive reports have been issued both by the United States Strategic Bombing Survey and the British Mission to Japan.

Table 1.10. Comparison of Casualties from Atomic and Conventional Bombs[1]

	Hiroshima Atomic Bomb	Nagasaki Atomic Bomb	Tokyo 1,667 tons Incendiary and TNT	Average of 93 Attacks 1,129 tons Incendiary and TNT per attack
Population per square mile	35,000	65,000	130,000	—
Square miles destroyed	4.7	1.8	15.8	1.8
Killed and missing	70,000	36,000	83,000	1,850
Injured	70,000	40,000	102,000	1,830
Mortality per square mile destroyed	15,000	20,000	5,200	1,000
Casualties per square mile destroyed	30,000	42,000	11,800	2,000

[1] "The Effects of Atomic Weapons," U.S. Government Printing Office, Washington, D.C.

Figure 1.06. Aerial photographs taken over Nagasaki before and after the atomic bomb explosion; circles of 1,000 and 2,000 feet radius are shown.

In addition, the Atomic Bomb Casualty Commission of the United States National Research Council, sponsored by the Atomic Energy Commission, is still (1951) in Japan investigating the possible delayed effects of the bomb on humans.

TEST ATOMIC EXPLOSIONS

The Alamogordo Test

1.12. The first atomic bomb actually to be exploded was that in the historic test held in the early hours of the morning of 16 July 1945, in a remote section of the Alamogordo Air Base in New Mexico. As seen above, the bomb proved to be a weapon of tremendous destructive power.

1.13. In the test at Alamogordo, the bomb was mounted on a steel tower, about 100 ft. above the ground. The great heat produced turned the steel into vapor, and the powerful force of the explosion caused a wide, shallow crater to form. The dirt and other debris disturbed by the blast was sucked up by a tremendous updraft, thus forming, with the residual bomb materials, a dense column of smoke. This rose rapidly to a height of nearly 5 miles before spreading out into the mushroom-shaped cloud characteristic of many atomic explosions.

1.14. Even before the explosion, most of the effects of the atomic bomb had been anticipated. Due precautions were accordingly taken to avoid injury to the personnel responsible for making observations both during and after the explosion. As a result, the bomb caused no casualties.

Operation CROSSROADS

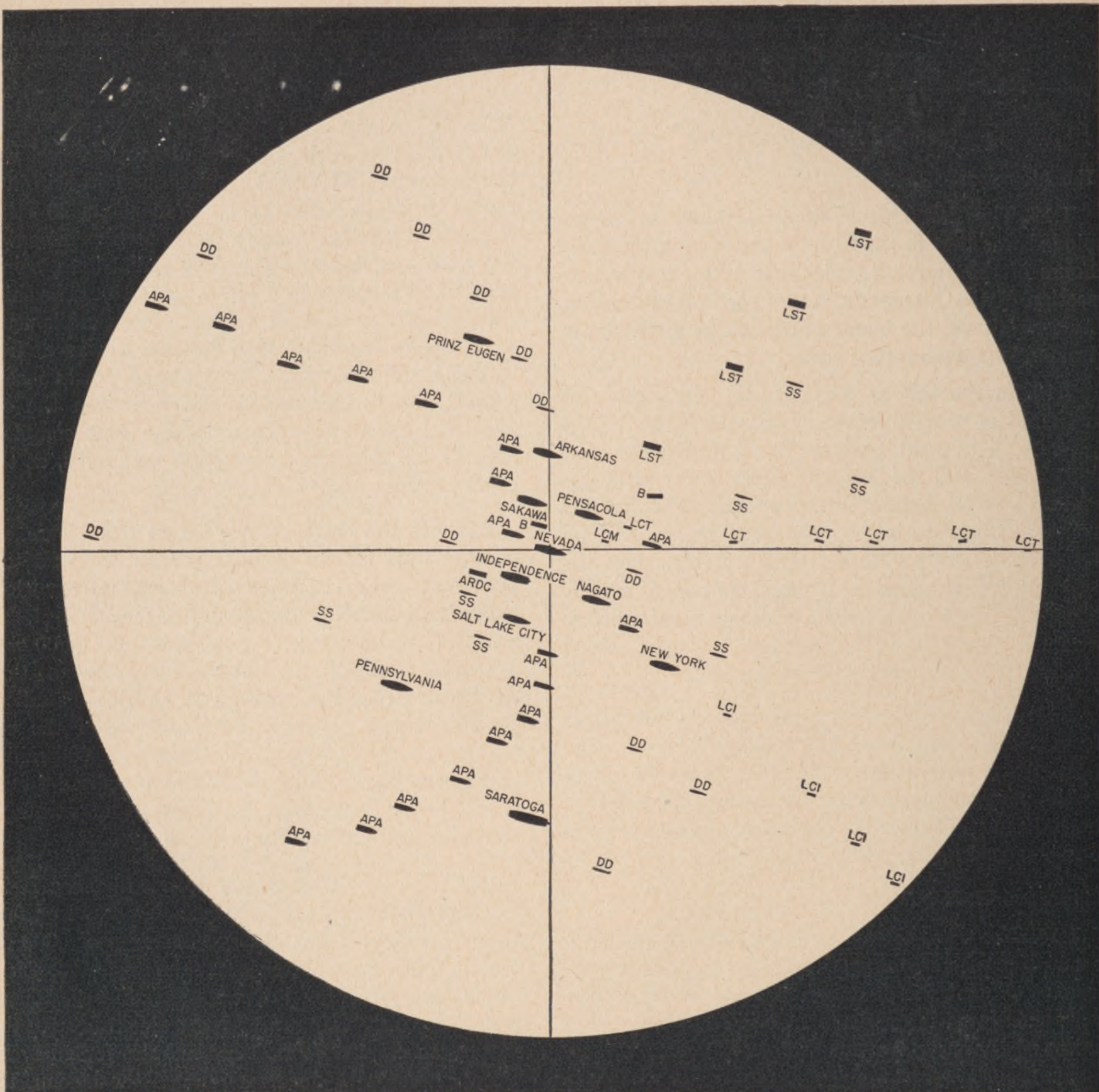
1.15. The three atomic explosions described above took place over land areas. In order to be in a position to protect the fleet in the event of an atomic war, the Navy, in particular, wished to know something of the effects of an atomic explosion at sea. Consequently, plans were set in motion for what was known as Operation CROSSROADS, a technical operation on a large scale, designed to supply data for naval and military defense against the atomic bomb. It was to be a joint effort of all the armed forces, and when actually carried out at Bikini in July 1946, it involved a total of 42,000 men, 242 ships, and 156 aircraft. Two bombs were exploded —one in the air (Test Able) and one under water (Test Baker). Among the 70 ships of various types forming the target array, there were 5 battleships, 2 aircraft carriers, 4 cruisers, 12 destroyers, 8 submarines, and many landing craft and merchant-type vessels.

Test Able

1.16. In Test Able, the central target vessel was the battleship NEVADA, and around it, within a radius of about 1,000 yards, were about 20 other ships. Outside this primary target area were spaced the remaining target ships along radial lines, somewhat like the spokes of a wheel (fig. 1.16). The ships were located much closer to each other than is usual under operating conditions because it was desired to obtain information as accurate as possible concerning the dependence on distance from the explosion of the whole range of damage, from complete loss, at one extreme, to complete immunity, at the other extreme.

1.17. On the decks of the target ships were exposed a wide variety of military equipment for test purposes: these included airplanes, ammunition, battle equipment, clothing, and packaged food. In addition, about 400 goats and pigs, and 5,000 rats were distributed throughout the target fleet so that the effects of the bomb on animals could be studied. To record the physical characteristics of the explosion, nearly 5,000 pressure gauges, 25,000 radiation-measuring instruments, 750 cameras and 4 television transmitters had been placed at strategic points on and around the target array.

1.18. The Test Able bomb, dropped from a B–29 flying at about 30,000 ft., burst a few hundred feet above the level of Bikini lagoon soon after 0900 on 1 July 1946. Immediately after the explosion, pilotless aircraft were flown over the target area. These planes, controlled by radio, were guided through the mushroom cloud to collect air samples for analysis. Then, planes with observers circled the lagoon, recording the damage visually and by means of cameras. A merchant-type vessel, the GILLIAM, the only target ship within 300 yards from surface zero, was seen to have sunk in less than a minute of the explosion. A destroyer, the ANDERSON, at less than 750 yards, was ablaze and sank in 8 minutes. Another merchant-type vessel, located about 1,000 yards from surface zero, sank some 40 minutes after the burst.



DD	DESTROYER	LST	LANDING SHIP TANK	LCM	LANDING CRAFT MECHANIZED
SS	SUBMARINE	LCI	LANDING CRAFT INFANTRY	ARDC	FLOATING DRYDOCK
APA	ATTACK TRANSPORT	LCT	LANDING CRAFT TANK	B	BARGE

Figure 1.16. Drawing of the Bikini Test Able target array as the bombardier might have seen it. In order to give accurate instrumentation of graded damage the concentration of ships was much higher than would normally be found in a tactical situation.

1.19. A second destroyer, the LAMSON, had capsized, and the Japanese cruiser SAKAWA was low in the water (fig. 1.19a). Both vessels sank slowly, the destroyer in 8 hours, and the cruiser on the morning of the day following the explosion. The light aircraft carrier INDEPENDENCE, less than 1,000 yards from surface zero, suffered severely (fig. 1.19b). The flight deck was bulged up and broken and the four stacks were demolished (fig. 6.97). Fire broke out on the hangar deck, adding to the general destruction.

1.20. Nearly all vessels within 1,000 yards of surface zero at the Bikini Test Able were either sunk or so badly damaged as to seriously impair their military efficiency. Moderate damage extended out to about 1,500 yards, and minor damage was experienced within a radius of 2,000 yards. Although the conditions of the explosion were not quite the same as those in the air bursts over Japan, it would seem that the area over which warships would suffer damage due to an atomic bomb is considerably less than for structures on land. This is to be expected, since warships are built to withstand a reasonable amount of blast. Military vehicles, such as tanks, which were exposed on the decks of some of the target ships, also proved to be resistant to damage. However, aircraft, similarly exposed, were found, by comparison, to be very vulnerable.

1.21. The number of fires aboard the ships was small. This was partly due to the relative absence of combustible matter on the decks. Such fires as did occur were mainly in packaged goods exposed for the test.

1.22. Patrols entered the lagoon about 2 hours after the detonation to determine whether it had been appreciably contaminated by the residue from the air-burst atomic bomb. Only a few areas were found to present any hazard, and in midafternoon the entire region was declared safe. The observing fleet then entered the lagoon. By sundown, 18 target vessels had been boarded and the recovery of scientific instruments and test animals was in progress. During the following week, inspection teams made a detailed examination of the damage suffered by the target ships and their contents.

Test Baker

1.23. The four preceding atomic explosions had all taken place in the air, and so Test Baker at Bikini presented a new feature, namely, an underwater burst. The bomb, in a watertight caisson, was suspended by a steel cable below a small landing vessel, the LSM–60. Around this was a new target array, again consisting of 70 ships of various types; 40 of these were within a mile of the LSM–60, while the others lay farther out. Each target vessel was fitted with gauges to determine strains in the hull, and with devices for measuring radiations that might arise from the exploding bomb. Instruments for determining underwater shock pressures and wave heights were placed in suitable positions.

1.24. At 0835 on 25 July 1946, the atomic bomb under the surface of Bikini lagoon was exploded by means of a radio signal. Instantaneously, a luminosity appeared in the water, rapidly followed by the formation of a dome-shaped bulge in the surface above the point of burst. A fraction of a second later a great hollow column or pillar of water began to rise at a great speed. This column, attaining a diameter of more than 600 yards, rose to a height of over a mile. The hollow stem, with walls believed to be some 100 yards thick, was capped by a huge cloud, giving the over-all appearance of a gigantic cauliflower (fig. 1.24). The total weight of water carried upward in the column was estimated to be well over a million tons.

1.25. Within a few seconds of the explosion, water from the column began to fall back into the lagoon and there developed at the surface, around the base of the hollow pillar, a great wave or cloud of mist, similar to clouds of spray formed at the bottom of Niagara Falls or other large waterfalls. This dense mist, which can be seen above the surface of the lagoon in figure 1.25, represents the initial stage of what has become known as the *base surge*.

1.26. In a very short time, the base surge cloud was roughly 1,000 feet high and moving rapidly outward, maintaining an ever-expanding, doughnut-shaped form. In about 3 minutes it reached its greatest expansion with an over-all diameter of some 3 miles. Then it drifted downwind, appearing gradually to lift from the surface of the water and merging with the cauliflower-shaped cloud (fig. 1.26). Some 15 minutes later the base surge cloud was entirely clear of the target array and was being lost among the natural clouds of the sky.

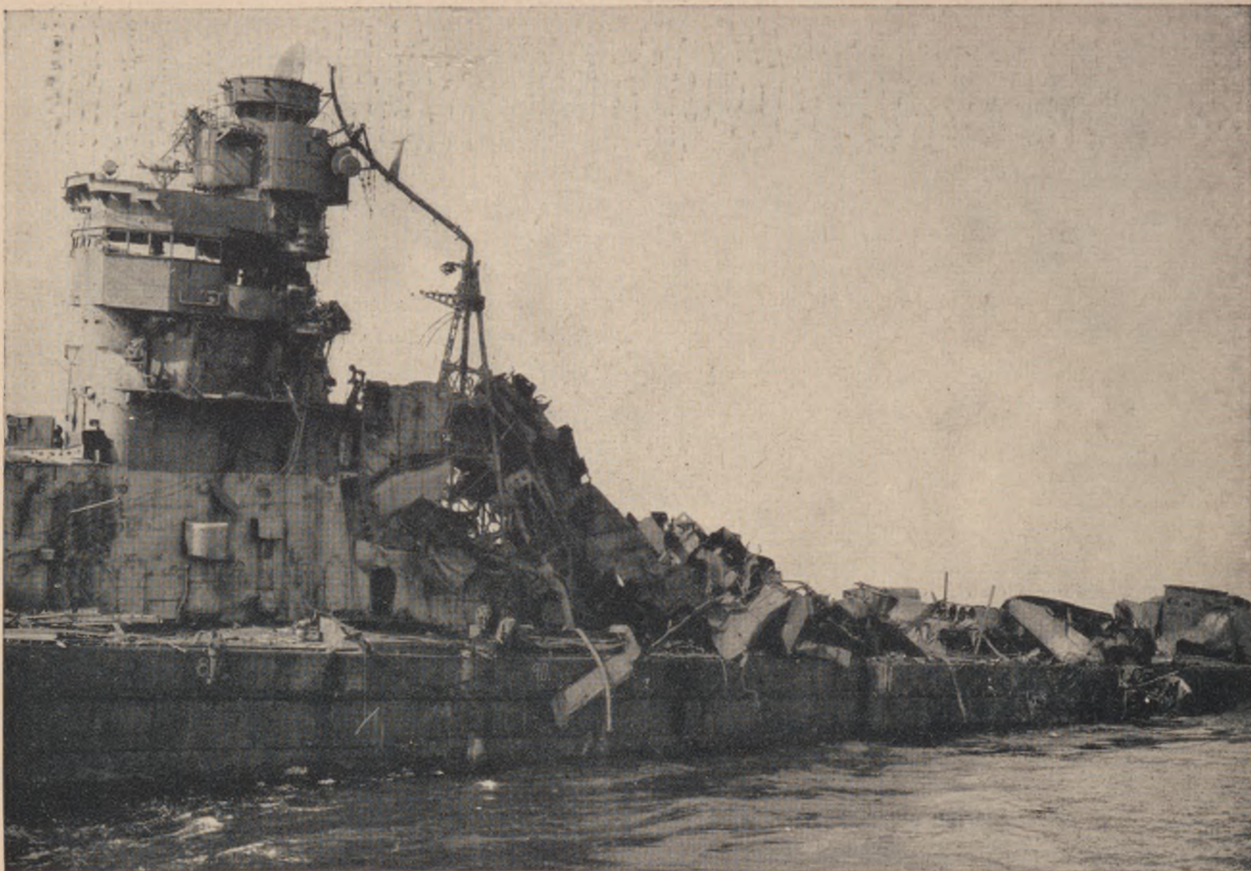


Figure 1.19a. The Japanese cruiser SAKAWA after Test Able at Bikini.

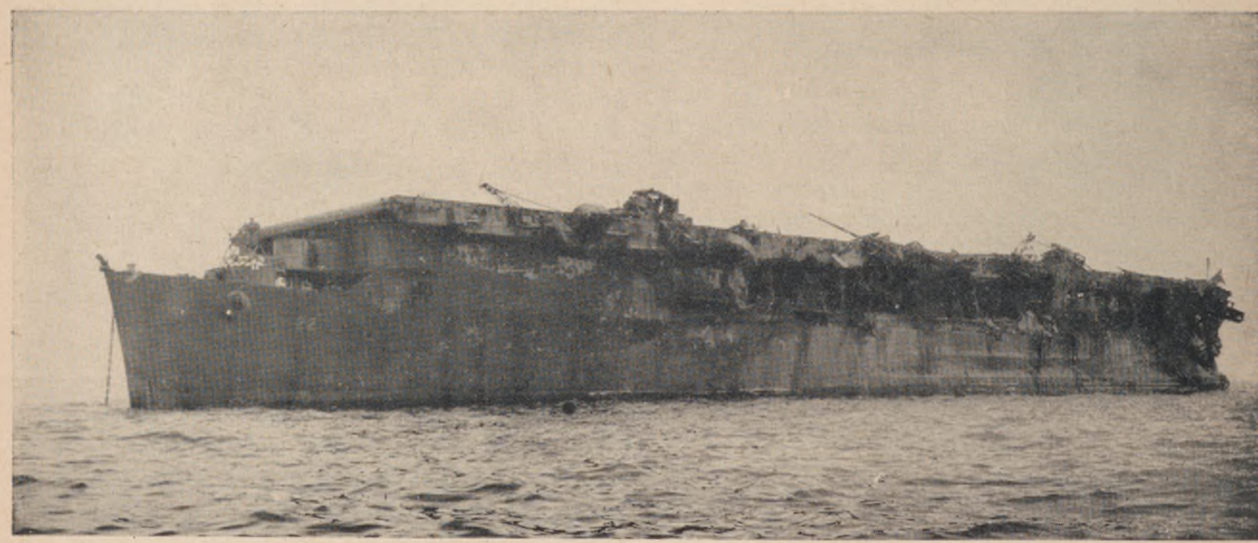


Figure 1.19b. The light aircraft carrier INDEPENDENCE after Test Able at Bikini.

Figure 1.24. The water column and "cauliflower" cloud formed by the underwater atomic explosion (Test Baker) at Bikini.

1.27. An intermittent, moderate rainfall, moving with the wind and lasting for nearly an hour after the explosion, developed from the cloud system. In its early stages, the rain was augmented by large amounts of water falling from the cauliflower cloud, and carrying with them considerable quantities of radioactive material.

1.28. When the base surge lifted, it was seen that the 34-year old battleship ARKANSAS, which had been near the LSM–60, had sunk, as also had a concrete oil barge and a landing craft in the vicinity, as well as the LSM–60 itself. Later, it was found that three submerged submarines had also been sunk. The aircraft carrier SARATOGA was low in the

Figure 1.25. Initial stage of the base surge at the base of the water column in Test Baker.

water and listing slightly to starboard (fig. 1.28). Many other ships showed obvious signs of severe underwater damage. In addition, measurements indicated that part of the energy produced by the explosion under water had been transmitted to the air. Because the water absorbed most of the heat from the bomb, there were no fires.

1.29. At first it was thought that the SARATOGA might be beached for examination, and salvage tugs entered the lagoon for the purpose. But it soon became apparent that the radioactive contamination of the carrier and the surrounding water was such that it might involve a hazard exceeding the rigorous tolerance limits imposed for the test operation. The

Figure 1.26. The base surge merging with the natural clouds of the sky.

tugs were therefore ordered to withdraw while the crippled SARATOGA slowly sank, disappearing completely under the surface of the lagoon by late afternoon.

1.30. In connection with contamination after the burst, Test Baker had an unexpected result from which important defensive lessons have been learned. The amount of water thrown into the air by the explosion had been predicted quite accurately, but some of the consequences of its return to the lagoon, particularly the base surge, had not been anticipated. The drops of water constituting the base surge cloud were highly contaminated with the residue from the

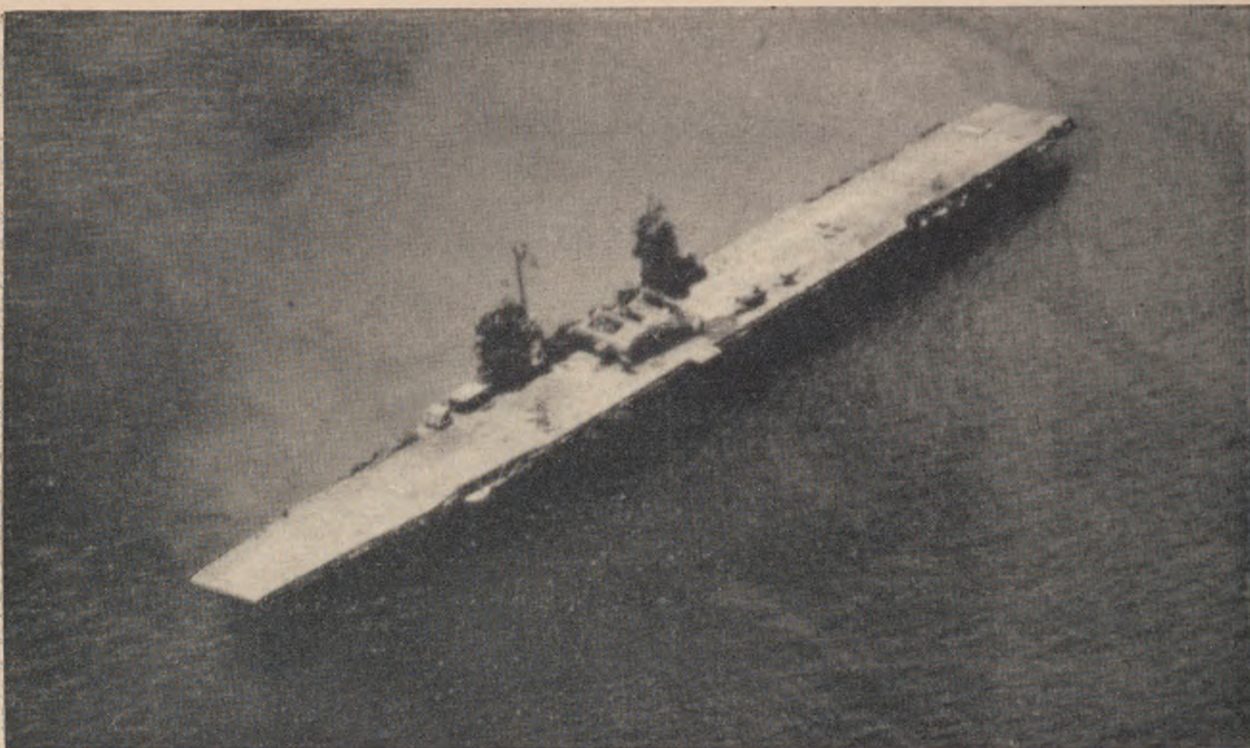


Figure 1.28. The aircraft carrier SARATOGA, several hours after Test Baker at Bikini. The damage to the stacks was not produced by air blast, but by mass movement of water.

atomic bomb, and these droplets, passing over and falling on ships, left them in a condition hazardous to human life.

1.31. Before the target vessels could be boarded, it was necessary to remove or decrease the radioactive contamination. This contamination cannot be neutralized nor destroyed, but it may be diminished in two ways. First, it may be washed, scrubbed, or blasted off, in one manner or another, from the surface to which it is attached, and thus diluted and transferred elsewhere, for example, into the sea. And second, advantage may be taken of the fact that all radioactive material undergoes a spontaneous decrease of activity with time, usually referred to as radioactive decay.

1.32. In general, both methods were used at Bikini following Test Baker. After the lapse of a few days, the contamination had decayed sufficiently to permit personnel to approach all ships without exceeding the tolerance limits which had been established for this peacetime operation. Then various emergency measures were adopted for preliminary decontamination to remove some of the radioactive material, so that the ships could be returned to the United States for examination.

1.33. A study of the damage provided valuable data to be used in the design of ships which might be subject to atomic attack. In addition, systematic efforts were made to develop simple and effective decontamination procedures. It is of interest to mention that two contaminated submarines were cleaned and returned to service free from risk to operating personnel. On the other hand, because of its battered condition no attempt was made to decontaminate the small aircraft carrier INDEPENDENCE. Yet, long before the vessel was disposed of, the natural decay had so decreased the radioactive contamination that the vessel could be occupied with complete safety.

Further Tests

1.34. In April and May, 1948, three atomic weapons of new design were tested at the United States Atomic Energy Commission Proving Ground on

Eniwetok Atoll, in the Marshall Islands. The major emphasis was on the scientific and technical aspects of weapons development. But, at the same time, important information, particularly in connection with the various radiations emitted by the bomb, was obtained that could be used for defensive purposes.

1.35. During 1951, further studies of the effects of atomic explosions have been made, both in the continental United States, at the Nevada Proving Ground, and at Eniwetok. The data obtained have served to improve our knowledge and understanding of atomic weapons. Much of the material contained in this manual is based on measurements and observations made at the various tests.

Atomic Explosions in Russia

1.36. The place of atomic defense in the nation's plans was given increased emphasis on 23 September 1949. On that day the President of the United States, in a brief announcement, told the world that this country was no longer the sole possessor of the atomic bomb.

"We have evidence that within recent weeks an atomic explosion occurred in the U. S. S. R.," the President said. "Ever since atomic energy was first released by man, the eventual development of this new force by other nations was to be expected * * *." Two additional Russian atomic explosions were announced by the President in October 1951.

CONCLUSION

1.37. The fact that a single bomb, which can be carried by a single plane, can cause essentially the same damage as TNT bombs requiring a thousand planes, has opened up a new era in offensive warfare. But, throughout history, the introduction of a new weapon has always been followed by the development of protective measures which have lessened its effectiveness. And in this respect the atomic bomb is no exception.

1.38. Since the atomic bomb is a relatively new weapon, it is evident that the history of atomic defense is short. Nevertheless, organizations in each branch of the armed forces have been making intensive studies of the problems of defense in atomic warfare. Every item of information, accumulated at Alamogordo, Hiroshima, Nagasaki, Bikini, Eniwetok and Nevada, as well as experience gained from other types of warfare, has contributed to the store of defensive knowledge. From this knowledge, new methods of coping with atomic attack are being devised.

1.39. The atomic weapon is known to be in the hands of at least one other power, and might consequently be used against this country's troops, ships, installations, and cities. Thus, an understanding of the characteristics of the atomic bomb and of the defensive measures which can be used to decrease its effectiveness is vital to all members of the Armed Services.

SUMMARY

The history of atomic defense began with the explosion of the bomb over Hiroshima, Japan, on 6 August 1945. This was the first time an atomic weapon had been used in warfare. Because of a lack of preparation and the fact that much of the population was in the streets at the time of the explosion, the proportion of casualties was high. Three days after the attack on Hiroshima, an atomic bomb was dropped on Nagasaki, Japan. Due to the nature of the terrain and the direction of the wind, and the fact that fewer people were in the open, the proportion of casualties at Nagasaki was smaller.

After the war, trained observers went to Japan to make detailed studies of the effects of the atomic bombings on structures and personnel. In this way, much information vital to the planning and organization of atomic defense has been obtained.

Operation CROSSROADS, carried out at Bikini in July 1946, was a large-scale technical operation, designed to supply data for naval and military defense against the atomic bomb. Two bombs were exploded: one in the air (Test Able) on 1 July 1946 and the other under water (Test Baker) on 25 July 1946. Subsequently, a number of other tests have been carried out and these have greatly improved our understanding of the effects of atomic explosions.

The information gathered at Hiroshima and Nagasaki, as well as that obtained from various test explosions, is being used as a basis for devising new methods of coping with the effects of the atomic bomb. Since the weapon is known to be in the hands of at least one other power, it is necessary that all members of the Armed Services should become familiar with its characteristics, and with the defensive measures which can be taken to decrease its effectiveness.

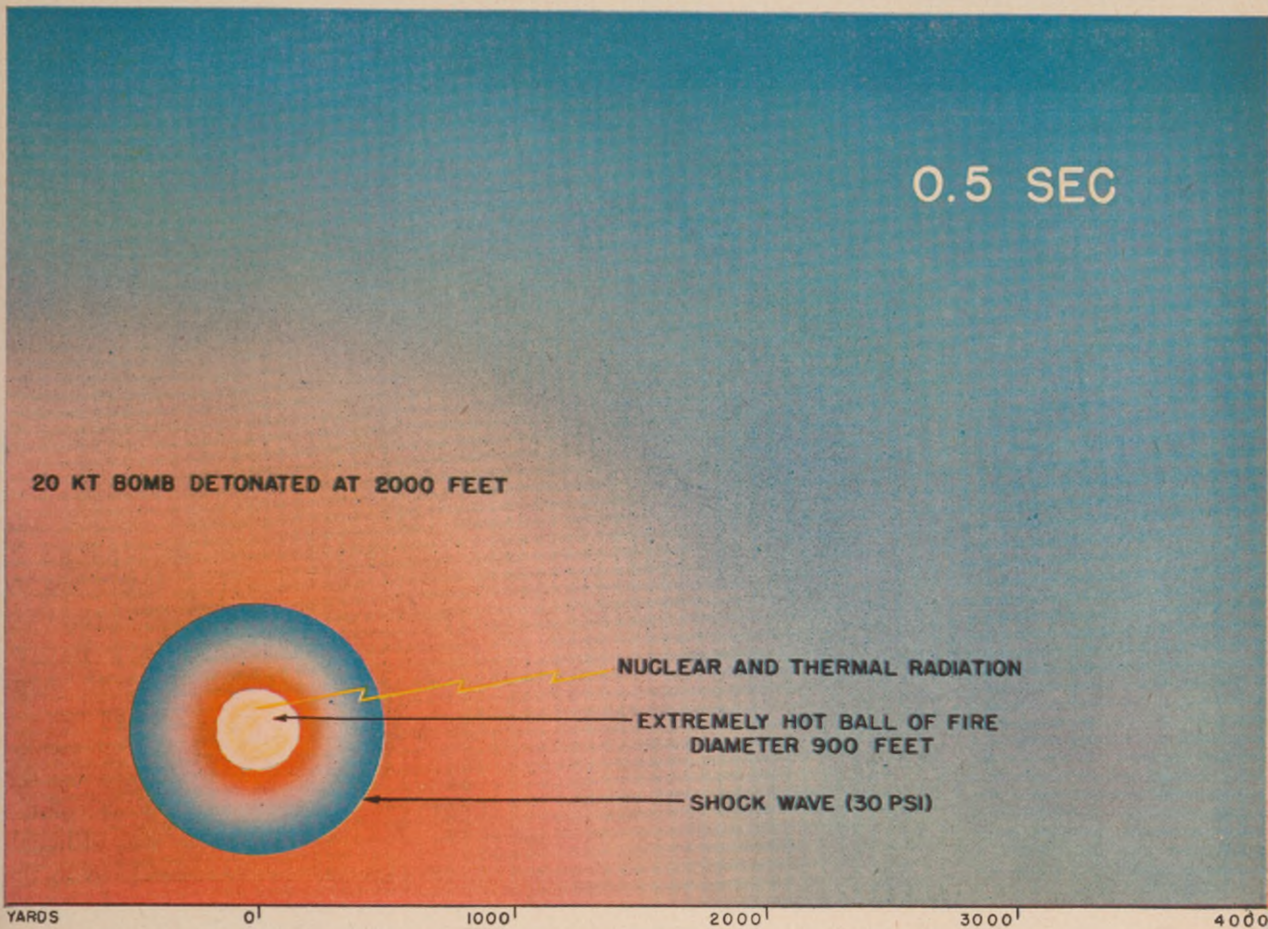


Figure 3.14a. Chronological development of an atomic air burst: 0.5 second after detonation.

Almost at the instant of detonation of an atomic bomb in the air, an intensely hot and luminous ball of fire forms. Due to its very high temperature, it emits thermal radiation capable of causing burns of exposed skin at a distance of 2 miles on a clear day. The explosion process and the radioactive decay of the resulting fission products are accompanied by nuclear radiations which are also emitted from the ball of fire. These radiations can cause injury to unprotected persons up to a mile or so away.

Very soon after the explosion a destructive shock or blast wave develops in the air and moves away from the ball of fire. At 0.5 second after the explosion of a "nominal" (20-kiloton TNT equivalent) atomic bomb in the air, the ball of fire has nearly attained its maximum size of 300 yards across. The shock wave has progressed roughly 250 yards ahead of the ball of fire, as indicated in the figure. The overpressure in the shock front, that is, the pressure in excess of the normal atmospheric pressure of 14.7 psi, is about 30 psi. For an air burst at a height of 2,000 feet, this shock wave will not have reached the ground by the end of 0.5 second.

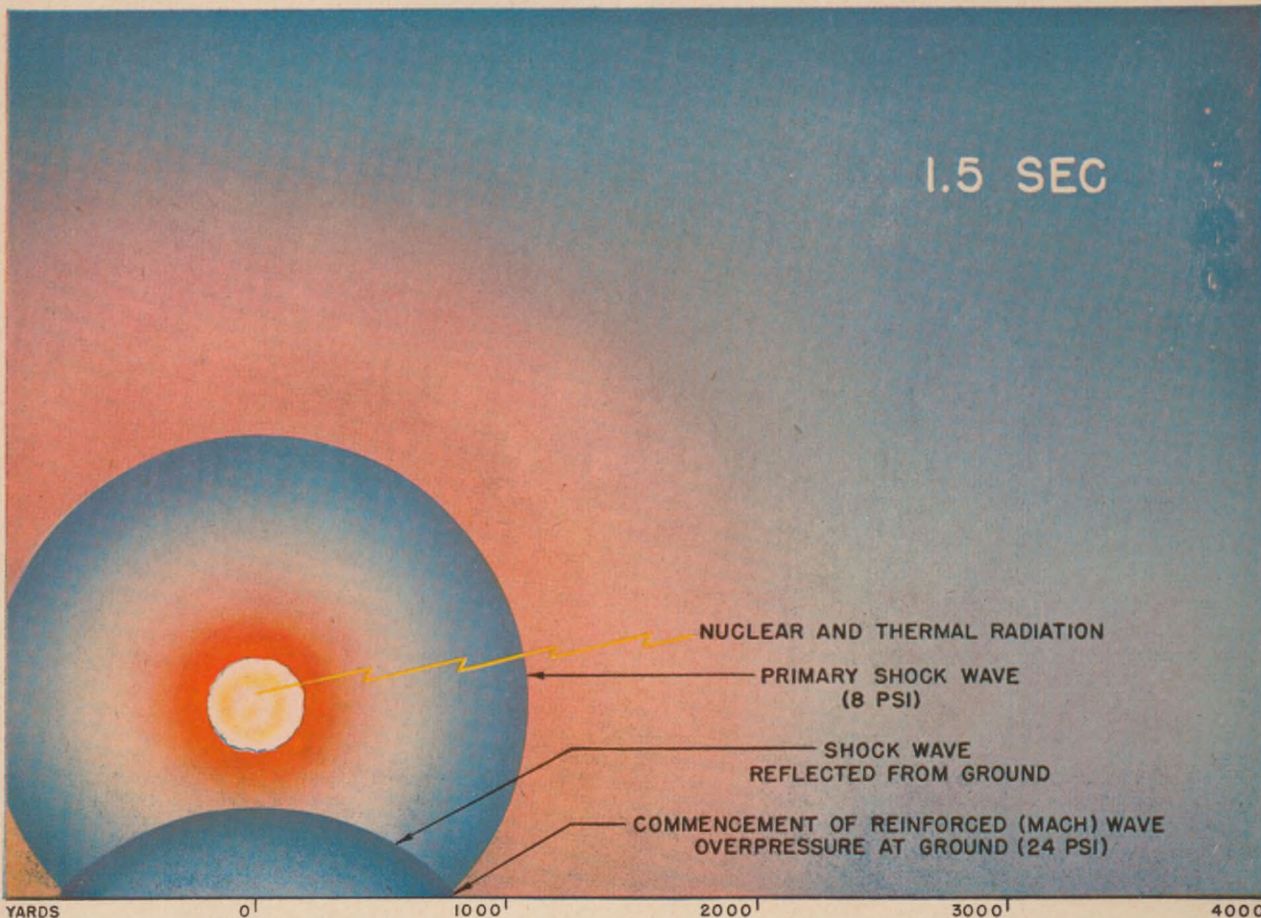


Figure 3.14b. Chronological development of an atomic air burst: 1.5 seconds after detonation.

The shock wave touches the earth's surface at about 0.7 second after the explosion and continues to move outward at a rate of roughly one-third of a mile per second (20 miles per minute). When this primary shock wave strikes the ground, another shock wave is produced by reflection. At a certain point, which depends upon the height of burst and the energy of the bomb, the primary and reflected shock waves fuse near the ground to form a reinforced wave, called the Mach wave. For the explosion of a nominal atomic bomb at an altitude of 2,000 feet, the fusion commences at about 1.5 seconds after the detonation. The shock front is then about 1,050 yards from the center of the explosion, or 750 yards from ground zero, as seen in the figure. The overpressure at the front of the primary shock wave in the air is 8 psi, but that of the reinforced Mach wave at the ground level is 24 psi. The fusion of the primary and reflected shock waves has thus resulted in a three-fold increase in the pressure of the air blast on the ground. Hence the Mach effect considerably enhances the destructive effect of the explosion.

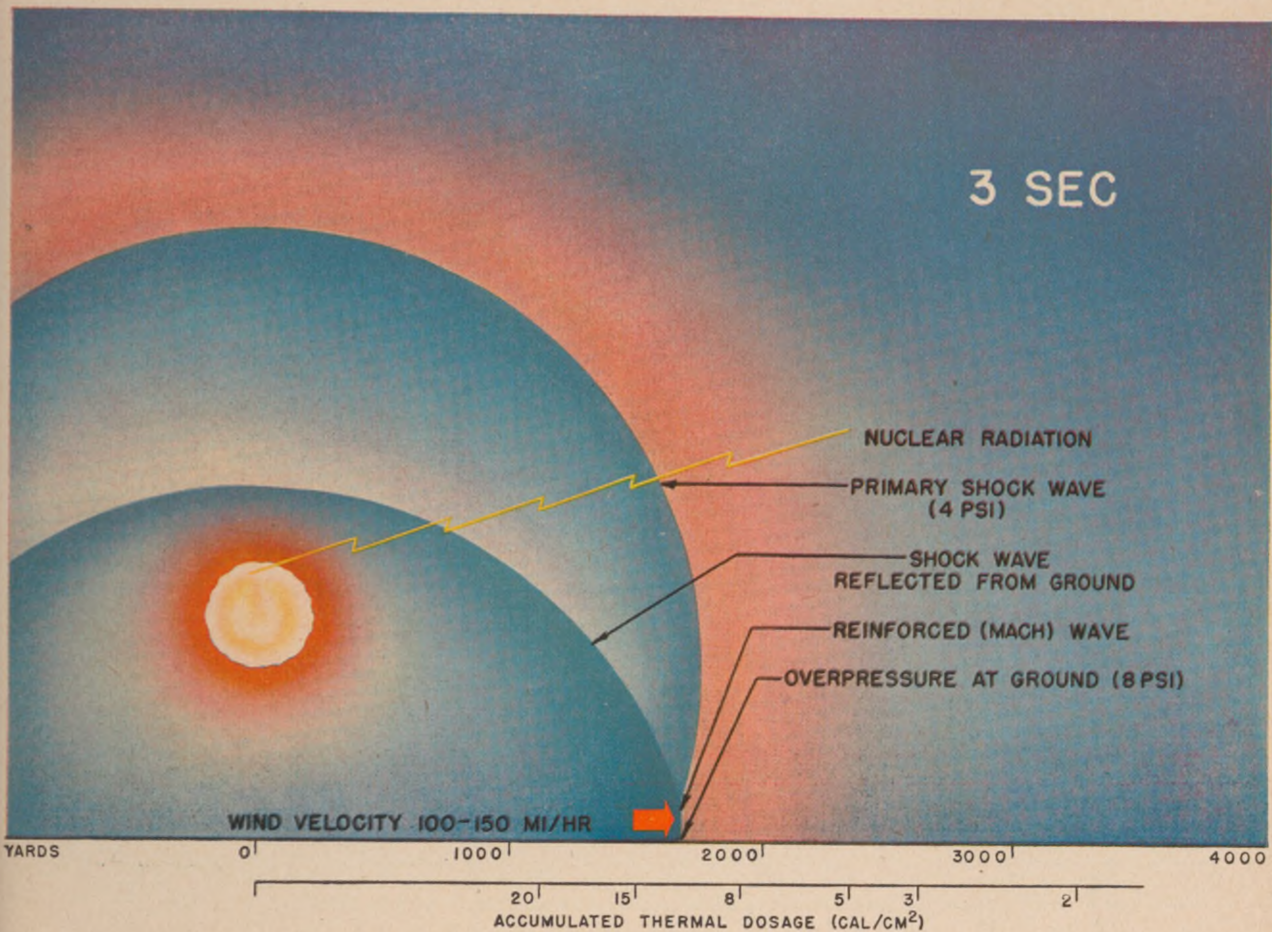


Figure 3.14c. Chronological development of an atomic air burst: 3 seconds after detonation.

As time progresses, the Mach wave front increases in height and moves outward, so that by the end of 3 seconds after the explosion it is more than 1,600 yards from ground zero. The overpressure on the ground at the front of the Mach wave is about 8 psi, compared with 4 psi of the primary shock wave in the air. The wind velocity on the ground is 100 to 150 miles per hour, and the air blast has considerable destructive potential.

The interior of the ball of fire is still very hot at 3 seconds after the explosion, but the surface has cooled to such an extent that the thermal radiation is no longer significant. Nuclear radiation, however, from the ball of fire continues to reach the ground.

The total accumulated doses of thermal radiation, expressed in calories per sq. cm., received at various distances from ground zero on a moderately clear day, are shown on the scale below the figure.

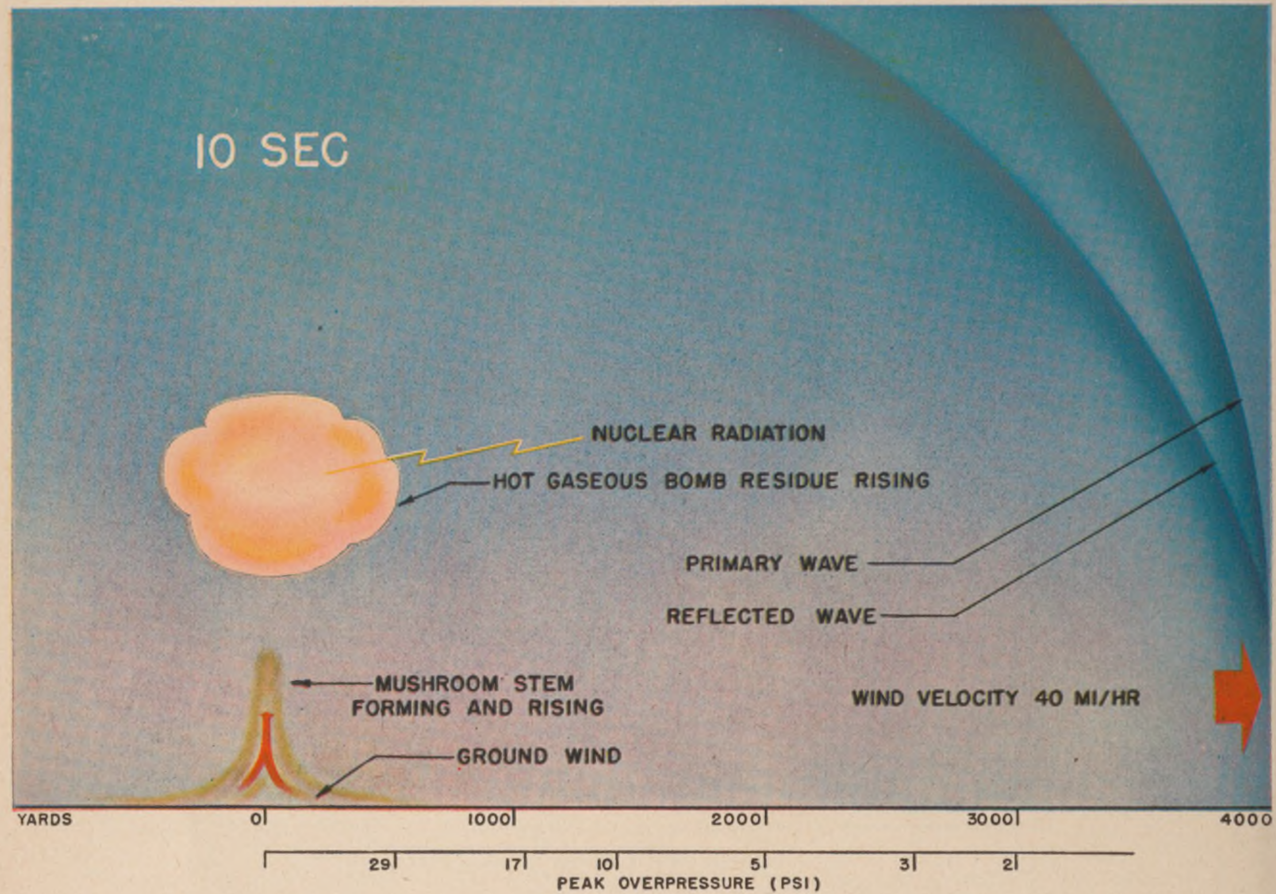


Figure 3.14d. Chronological development of an atomic air burst: 10 seconds after detonation.

After 10 seconds, the shock wave has progressed nearly 2½ miles from ground zero. Although the wind velocity near the ground is about 40 miles per hour, the overpressure at the front of the Mach wave is only about 1 psi. Consequently, apart from plaster damage and window breakage, the destructive effect of the shock wave is essentially over.

The ball of fire is now no longer luminous. However, it is still very hot, so that the gaseous residue from the bomb behaves like a hot-air balloon, rising at the rate of about 220 feet per second (150 miles per hour). As it rises, it causes air to be drawn inward and upward, somewhat similar to the updraft of a chimney. This produces a ground wind which raises dirt and debris from the earth's surface to form the stem of what will eventually be the characteristic mushroom cloud.

The scale at the bottom of the figure shows the maximum or peak values of the overpressure on the ground attained in the shock wave during its outward motion.

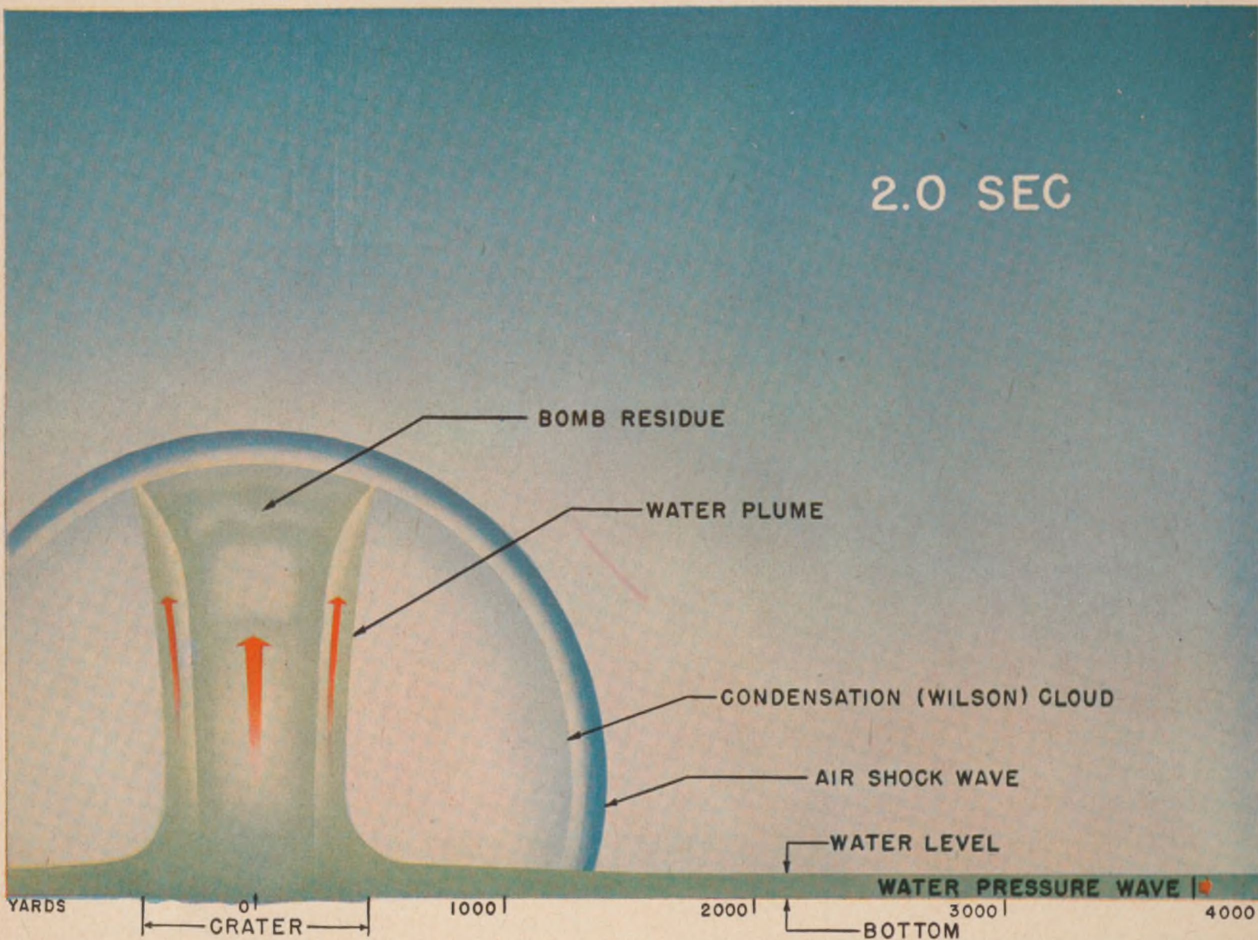


Figure 4.10a. Chronological development of a shallow underwater burst: 2.0 seconds after detonation.

When an atomic bomb is exploded under the surface of the water, essentially all of the instantaneous nuclear radiations and the thermal radiation are absorbed by the water. If the detonation occurs at a moderate depth, the bubble of hot gases will burst through the surface. As a result, a hollow chimney or "plume" of water and spray is shot upward, reaching a height of nearly 5,000 feet in 2 seconds. The gaseous bomb residue is then vented through the hollow central portion of the plume.

The explosion under water causes a shock wave to move outward, just as in the case of an air burst. The shock wave in water, however, travels more rapidly than in air, so that the front is more than 2 miles from surface zero at the end of 2 seconds. The expulsion of the hot gas bubble also produces a shock wave in the air as shown in the figure. The energy of the air blast is about one-fourth that due to the detonation of a nominal atomic bomb in the air.

After the air shock wave has passed, a dome-shaped cloud of condensed water droplets, called the Wilson cloud, is formed for a few seconds. While this phenomenon is of scientific interest, it has no significance as far as atomic attack or defense is concerned.

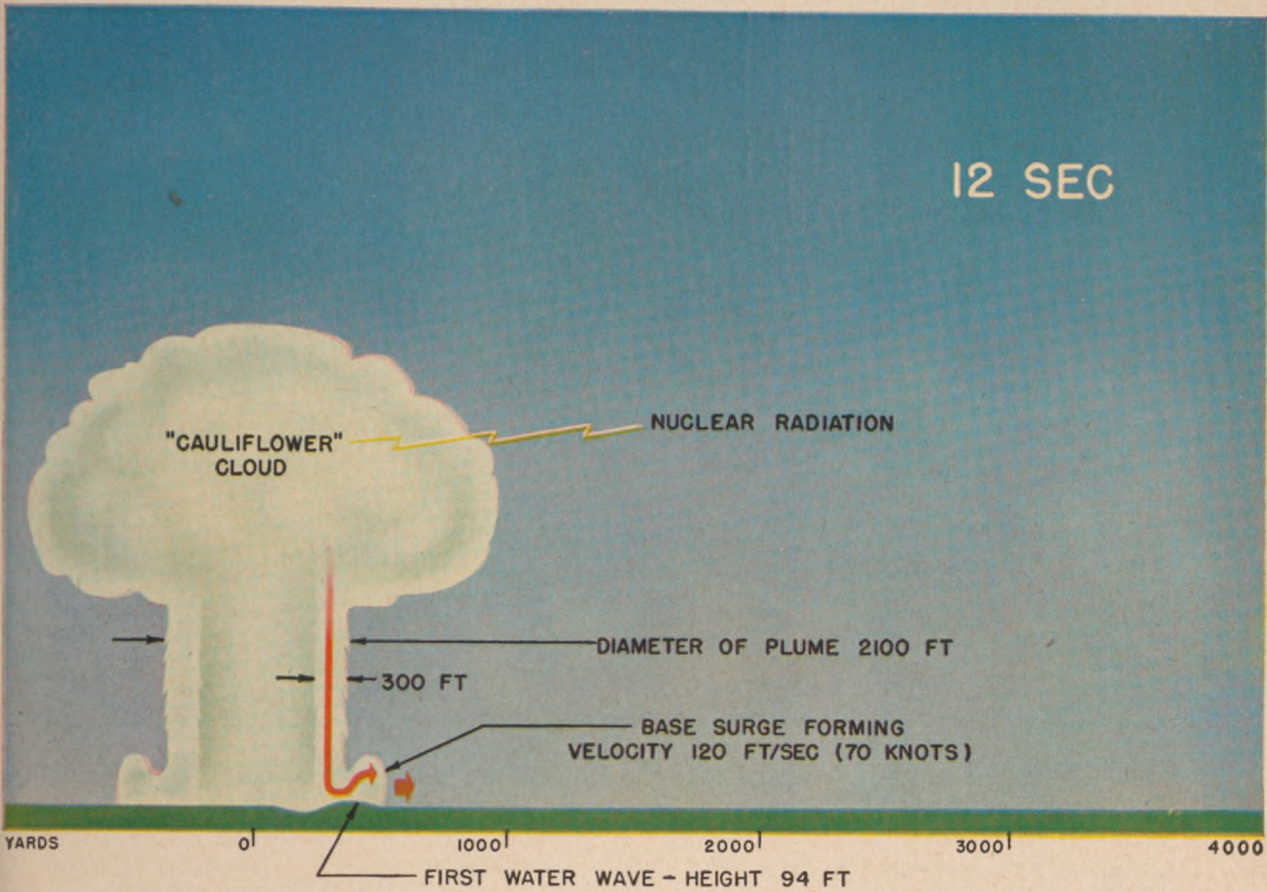


Figure 4.10b. Chronological development of a shallow underwater burst: 12 seconds after detonation.

At 12 seconds after the explosion, the diameter of the plume is about 2,100 feet, and its walls of water and spray are some 300 feet thick. The bomb residue venting through the central hollow portion spreads out to form the cauliflower-shaped atomic cloud, partly obscuring the top of the plume. The cloud is highly radioactive, due to the presence of fission products, and hence it emits nuclear radiations. But the distance from the surface is too great for these to be a significant hazard to personnel on ships surviving the explosion.

At 10 to 12 seconds after the underwater burst at Bikini, the water falling back from the plume reached the surface of the lagoon and produced around the base of the column a ring of highly radioactive mist, called the base surge. This ring-shaped cloud moved outward at the rate of about 120 feet per second (70 knots), parallel to the water surface.

The disturbance due to the underwater explosion caused large water waves to form. After 12 seconds, the first of these was 300 to 400 yards from surface zero, and its height, from crest to trough, was 94 feet.

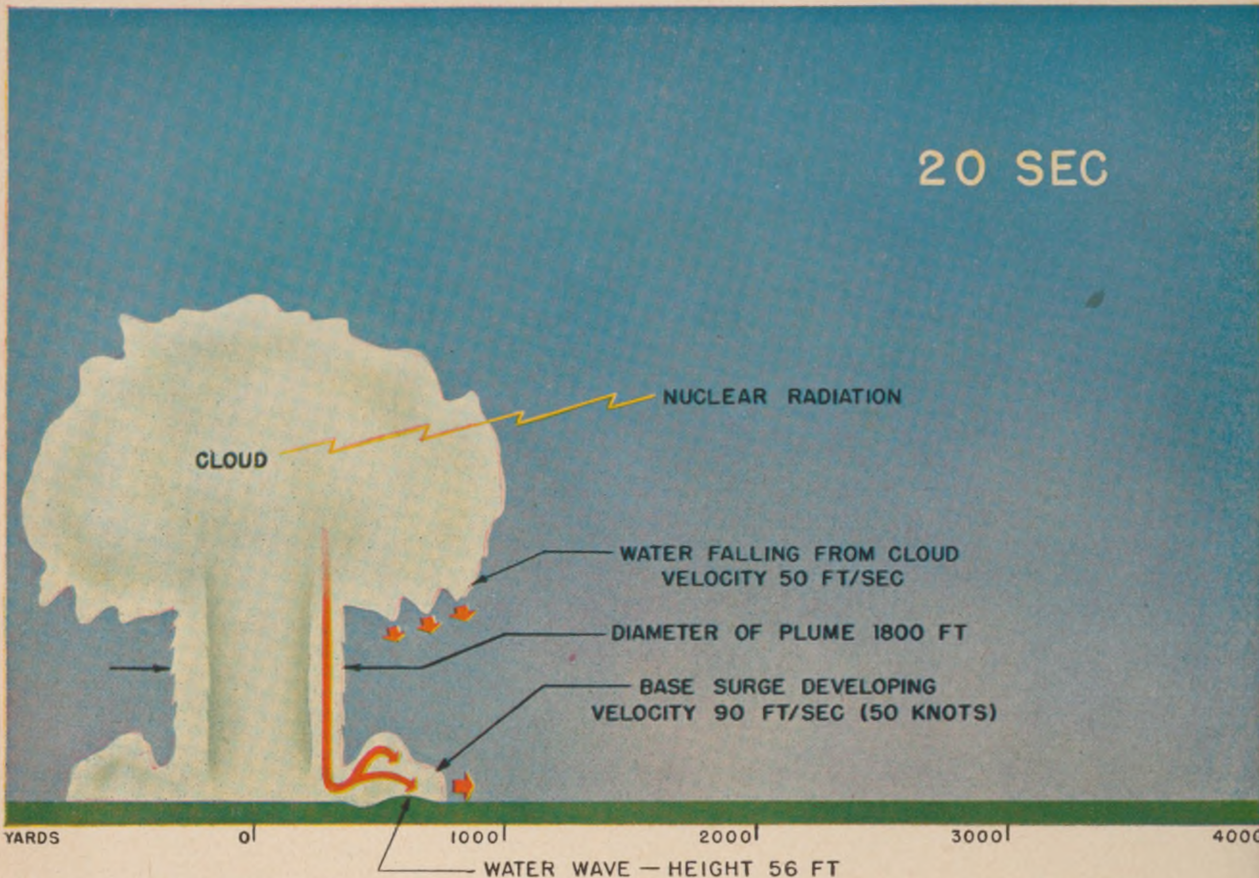


Figure 4.10c. Chronological development of a shallow underwater burst: 20 seconds after detonation.

As the water and spray forming the plume at Bikini continued to descend, the base surge cloud developed. The highly radioactive ring of mist billowed upward and moved outward across the surface of the water. At 20 seconds after the explosion the height of the base surge was about 800 feet, and the front was some 700 yards from surface zero. It was then progressing outward at the rapid rate of approximately 90 feet per second (50 knots).

At about this time large quantities of water and spray, sometimes called the massive water fall-out, began to descend from the cauliflower cloud. Its initial rate of fall was about 50 feet per second. Because of the loss of water from the plume, in one way and another, its diameter had now decreased to 1,800 feet.

By the end of 20 seconds, the first water wave had reached 500 to 600 yards from surface zero, and its height, from crest to trough, was roughly 56 feet.

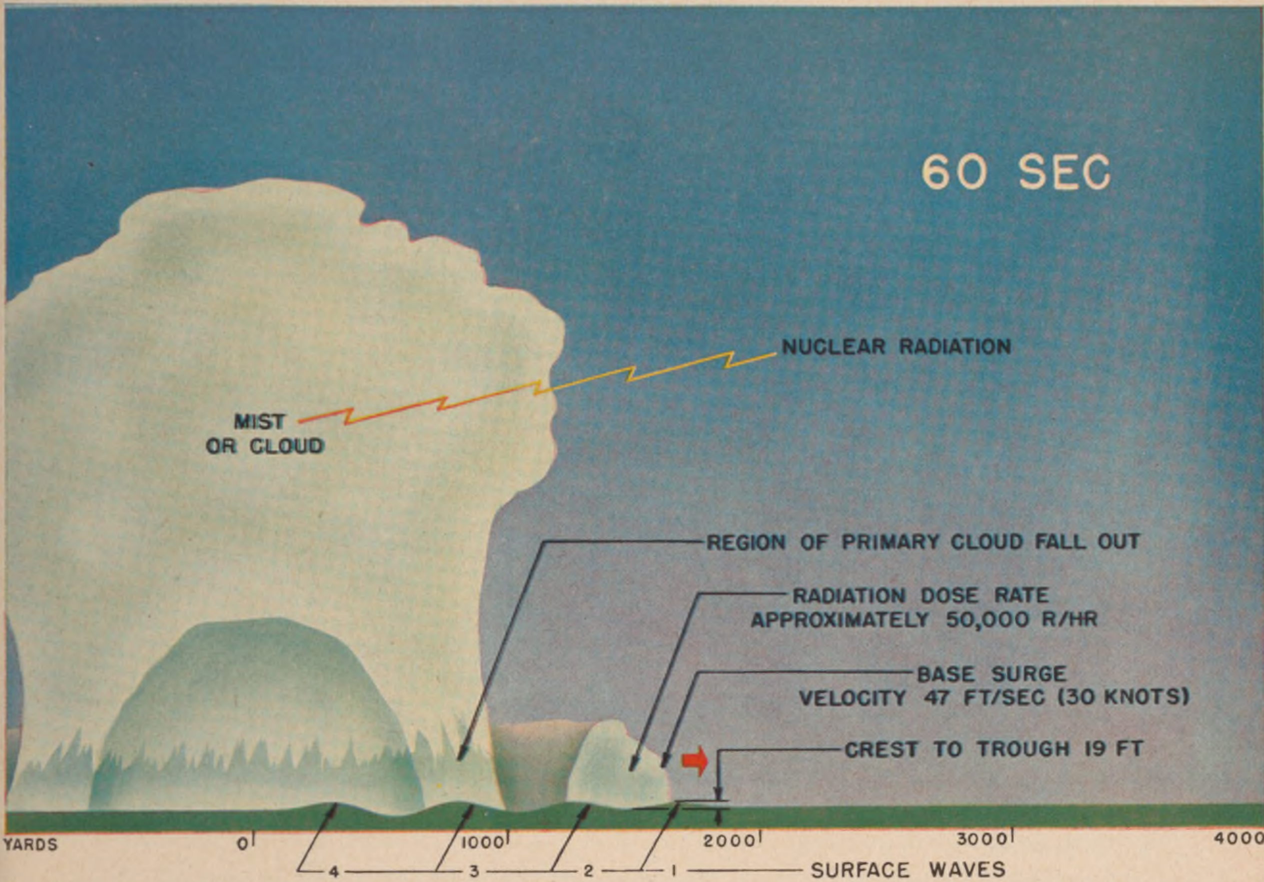


Figure 4.10d. Chronological development of a shallow underwater burst: 60 seconds after detonation.

At 60 seconds after the underwater burst at Bikini, the water falling from the cauliflower cloud just reached the surface of the lagoon, as indicated by the region of primary cloud fall-out in the figure. There was thus an essentially continuous ring of water and spray between the cloud and the surface.

At this time, the base surge cloud had become detached from the plume, so that its ring-like character was apparent, as shown in cross section in the figure. The height of the base surge was about 1,000 feet and its front, moving forward with a velocity of some 47 feet per second (30 knots), was approximately 1,600 yards from surface zero. Its intense radioactivity is indicated by the radiation dose rate of 50,000 roentgens per hour at 60 seconds after the detonation.

Several water waves have now developed, the first, with a height of 19 feet from crest to trough, being 1,600 to 1,700 yards from surface zero.

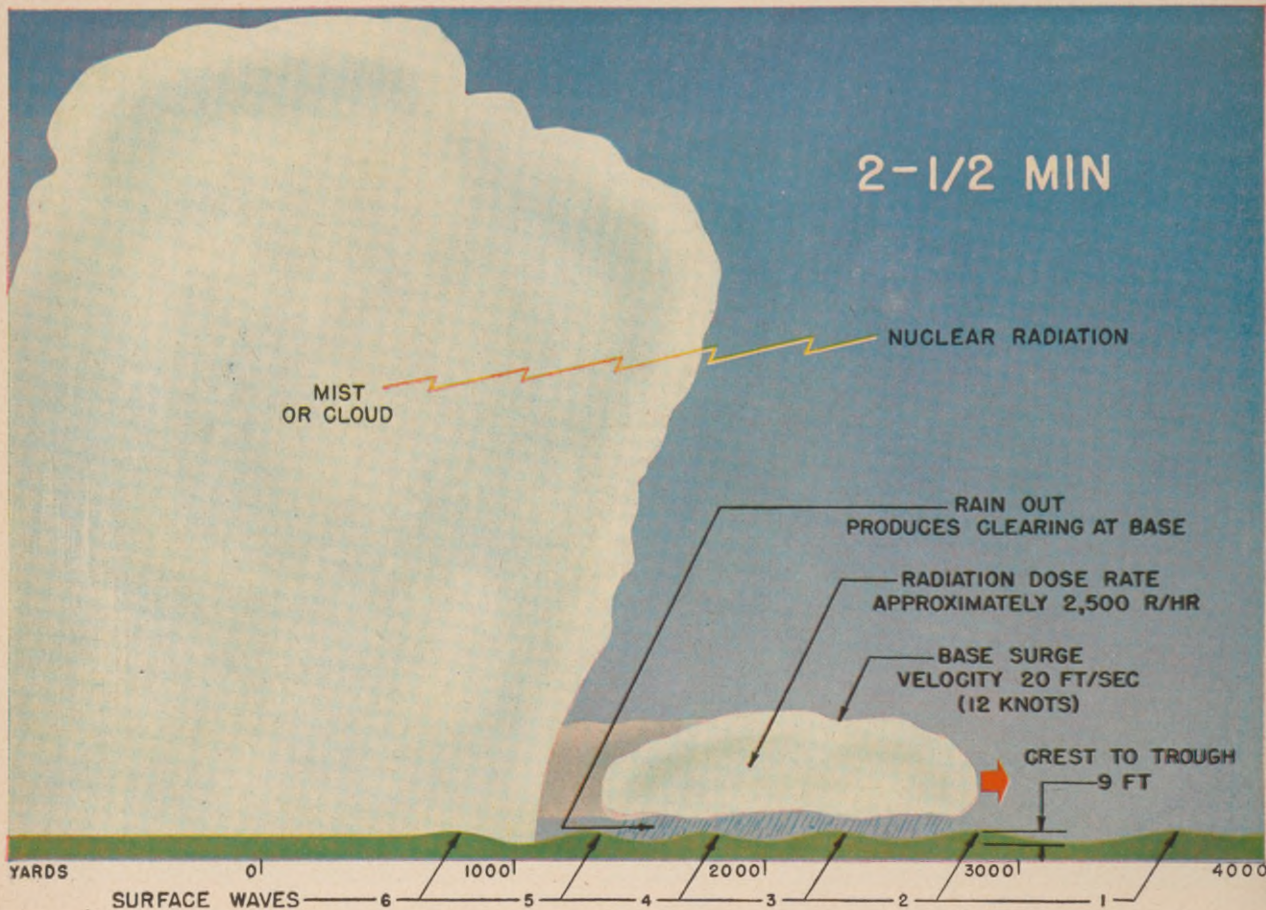


Figure 4.10e. Chronological development of a shallow underwater burst: 2½ minutes after detonation.

By 2½ minutes after the underwater explosion at Bikini, the front of the base surge was about 2,700 yards from surface zero and had almost attained its maximum thickness of roughly 1,800 feet. The greatest effective spread of the base surge, reached in roughly 4 minutes, was approximately 3,000 yards from surface zero, or nearly 3½ miles across. Owing to natural decay of the fission products, to condensation of the water, and thinning out of the mist by air, the nuclear radiation dose rate at 2½ minutes has decreased to 2,500 roentgens per hour. While this is much less than in figure 4.10d, it is still very considerable. At about this time, the base surge cloud appeared to be rising from the surface of the water. This effect was probably due to several factors, such as actual increase in altitude, thinning out of the cloud by engulfing air, and raining out of the larger drops of water.

The descent of water and spray from the plume and from condensation in the cauliflower cloud resulted in a continuous mass of mist or cloud down to the water surface. Ultimately, this merged with the base surge, which had spread and thinned out, and also with the natural clouds of the sky (fig. 1.26), to be finally dispersed by the wind.

Figure 4.48. Underground explosion of 160 tons of TNT conducted at Dugway Proving Ground, Utah, in May of 1951. The base surge can be clearly seen during the early stages of formation. The similarity of the appearance of this explosion with the underwater atomic explosion shown in fig. 1.25 should be noted.

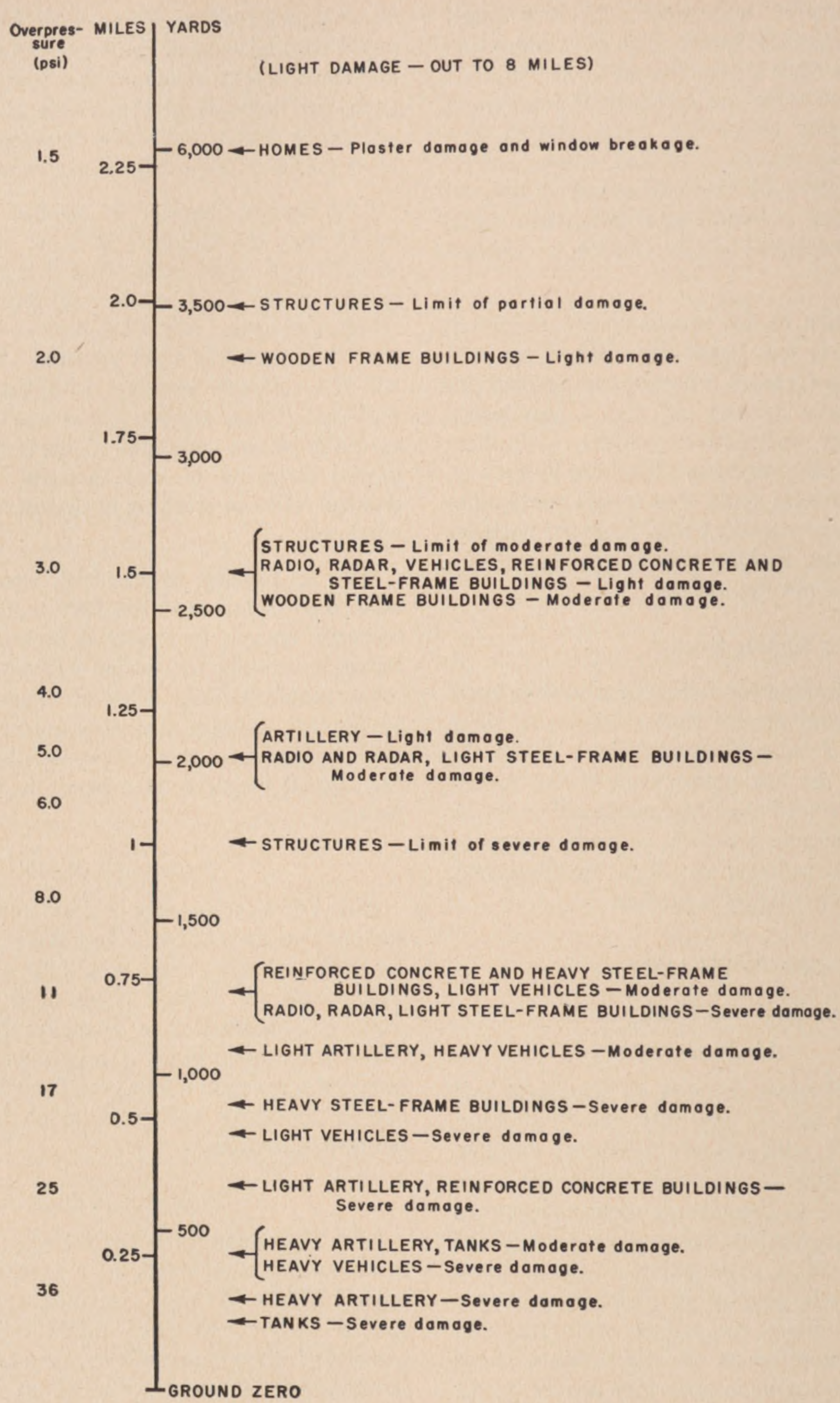


Table 6.59. Blast damage to various types of structures and matériel due to an air burst of a nominal atomic bomb at 2,000 feet altitud

Reinforced Concrete and Heavy Steel-Frame Buildings

6.71. While all types of structures can be damaged by sufficiently high blast pressures, some are less vulnerable than others. Reinforced concrete buildings and those with heavy steel frames are the most resistant types of construction (fig. 6.71). When partial failure occurs, for example, buckling or collapse of roof and floors, or fracture of columns, the undamaged members can often still carry the whole weight of the structure. In these circumstances, complete collapse will not occur, and the damaged portions of the building are more likely to distort than to break.

6.72. Reinforced concrete buildings are also the most fire resistant, for the concrete protects the steel structural members from the heat. However, if the contents of the building are combustible and continue to burn intensely for some hours, the concrete can crumble and thus expose the reinforcing steel. This may then be weakened by the heat and the building may collapse.

6.73. Because the strength of the steel members decreases markedly at moderately high temperatures, steel-frame buildings of all types are susceptible to serious structural damage by fire. As in the case of reinforced concrete buildings, the nature of the contents and interior construction is important in determining the extent of damage. If the structure has wooden walls and floors or contains combustible stores, the heat from the fire will cause steel members

Figure 6.71. Reinforced concrete building, 240 yards from ground zero in Japan. The walls are intact although the interior was destroyed by fire.

to weaken or to fail. Complete collapse of the building is then probable.

Light Steel-Frame Buildings

6.74. Many industrial buildings, repair shops, etc., have relatively light steel frames. In such buildings, fracture of supporting members and joint connections is not common, but the lightness of the frame makes mass distortion probable (fig. 6.74). Sheathing of corrugated iron or asbestos sheet is likely to be blown off, leaving only the frame standing. If such sheathing offers little resistance to the blast, the frame will suffer little or no structural damage. However, the contents of the building may be rendered useless by debris. The remarks made above with respect to the effect of fire on steel-frame buildings apply equally here.

Masonry and Brick Buildings

6.75. Heavily constructed masonry buildings may stand up well to blast because of their great size and weight. But, when the pressure is large enough to cause such a structure to distort slightly, or to fail locally, e.g., by breakage of mortar connections, the whole building may collapse. When such a masonry building does fail, the heavy structural material will cause severe damage to equipment and supplies in the interior. Light masonry and brick structures have little resistance to blast. The debris will bury equipment in the building, and will provide missiles which will injure persons in the vicinity.

6.76. Brick and masonry buildings with load-bearing walls if close enough to ground zero may be destroyed by the blast. If they are, the question of structural damage by fire is not important. However,

Figure 6.74. Light steel frame industrial building, 600 yards from ground zero in Japan. The roof and wall sheathing was stripped by the blast, and the combustible contents destroyed by fire.

fire can contribute to the damage independently by weakening the remaining supports, thus encouraging collapse of the building, and can add to the over-all destruction by consuming the contents.

Wooden Buildings

6.77. Owing to their light construction, wooden buildings have little rigidity and are easily deformed by air blast pressure. The nailed joints are relatively weak and can withstand little strain. Consequently, wooden buildings will quickly collapse as the result of an air burst. Even when they are beyond the range of severe destruction, they may suffer damage to roof, wall panels, and interior partitions. Stores and equipment inside the buildings are less likely to be damaged by the light debris, but, on account of the inflammability of the wooden structural material, they are more susceptible to destruction by fire.

Bridges, Highways, and Railroads

6.78. By virtue of their design, bridges are, on the whole, remarkably resistant to air blast. It was found after the atomic bombings of Japan that steel-girder bridges with reinforced concrete decks suffered relatively little (fig. 6.78). Even when there was some damage, such as destruction of road surface or shifting of the decks, they generally remained usable. In a few instances only was a span blown off its piers or abutment. However, an underground or surface burst would probably have proved more destructive. Long-span suspension bridges will stand a good chance of surviving an air burst because of their

Figure 6.78. Steel plate girder railway bridge, about 280 yards from ground zero in Japan. The plate girders were moved about 3 feet by the blast, but the bridge was essentially intact.

flexibility. Steel military bridges may be expected to resist blast almost as well as the permanent type. Emergency bridges of makeshift construction will probably not stand up well to an atomic explosion.

6.79. Highways, railway roadbeds, and rails are, on the whole, relatively invulnerable to damage by air blast. They may be covered by rubble and debris, but this can be removed. Even after a nearby surface or underground burst highways and railroads can be restored to operation without difficulty, if necessary by bypassing the severely damaged area. Railway rolling stock has the same vulnerability as other structures of a similar type.

Airfield Runways

6.80. Runways of airfields are built to withstand considerable pressure, and will probably not be seriously damaged by blast in an air burst. However, they may be expected to suffer severely from a surface or underground burst in the vicinity.

Tanks

6.81. Medium and heavy tanks and armored cars are very resistant to blast, shock, and thermal radiation. However, exposed equipment such as antennas, sighting mechanisms, lights, and machine-gun mounts are vulnerable. Tanks that are not properly buttoned up will suffer severe interior damage due to the entrance of the blast wave through ports and hatches. Near to the point of burst, such damage may occur even when the tank is buttoned up. The blast wave can then break through motor ventilation openings and the inspection plates between the motor and fighting compartments. The pressure build-up may blow hatch covers open. Furthermore, the blast wave may throw the tank some distance or overturn it. However, in spite of the possibility of damage, a medium or heavy tank will, in general, provide much protection against the effects of an atomic air burst.

Ordnance and Ammunition

6.82. While heavy weapons are somewhat more easily affected than heavy tanks, they are still very resistant to damage. Nevertheless, as with tanks, exposed parts, such as fire control equipment, will suffer. Ammunition is not as vulnerable to heat as might be expected. While exposed powder, such as artillery and mortar powder increments, can be ignited by thermal radiation, enclosed or encased ammunition is fairly resistant. Neither artillery shells nor small-arms ammunition will be affected by thermal radiation except, of course, near ground zero.

Vehicles

6.83. Essentially all types of vehicles, including jeeps, trucks, etc., and other mobile equipment will be subject to considerable damage due to direct action of the blast and shock or as a result of destruction of surrounding buildings. Overturning of vehicles or bumping of one against another will be contributory factors. Light damage will include breakage of windows, electrical equipment, and wiring, and infiltration of dirt or grit into the working parts of engines. Nearer to ground zero, wheels, exposed parts of the motor such as spark plugs and carburetors, tires and the body, may suffer in addition. In zones of heavy damage, there may also be warping of frames, collapse of roofs, and rupture of fuel tanks. In the latter event, ignition of the gasoline may result, and then there will be much fire damage. Thermal radiation may cause superficial damage to tires, paint, etc., but it will not ignite gasoline unless the tank is ruptured.

Electrical and Electronic Equipment and Machinery

6.84. Lightly constructed sensitive equipment, like switchboards, radar and radio sets, telephones, and radiation detection instruments, are highly vulnerable. Even if they are not directly affected by blast or shock, they can be ruined by debris or fire. Heavier equipment, for example, machine tools, motors, and generators can also be damaged by debris and by fire. Valuable industrial equipment, even if undamaged by blast, debris, or fire, can be rendered useless by rust due to exposure to the elements (fig. 6.84). Consequently, machinery of all kinds will suffer less in reinforced concrete or heavy steel-frame buildings than in light metal or wooden construction.

Public Utility Lines

6.85. Poles carrying overhead power and telephone lines are vulnerable to blast, shock, and fire and may be seriously damaged. The lines themselves may be blown down by the blast beyond the distance where the poles are more or less intact. Water and gas distribution lines running above the surface may suffer

Figure 6.84. Machinery lightly damaged by debris and by fire, but exposed to the elements after the atomic attack on Japan.

breakage, either due to the air blast or to the destruction of the buildings through which they pass.

6.86. In the case of an air burst, underground distribution lines usually will be undamaged, except directly below the burst, where ground shock may be responsible for damage to sewer pipes and drains at shallow depths. Damage to buried pipes and fittings may result from the weight of the debris on the ground above them.

6.87. All underground utilities will suffer greatly from the displacement of the ground and the shock pressure due to a subsurface explosion. Sewer, gas and water mains will be particularly susceptible. It is possible that electric mains will suffer much less because of their ductility. However, above-ground lines may be broken as a result of tower and pole distortion, caused by the earth shock.

Supply Dumps

6.88. Supply dumps have little exterior protection and are therefore subject to considerable damage and destruction by blast, shock and fire unless dug in as described in paragraph 12.30. Gasoline and oil dumps will be particularly vulnerable, because rupture of containers may well be followed by serious fires. Ration and ammunition dumps will, on the whole, probably suffer less severely unless fire breaks out.

Rations and Water

6.89. In the event of an air burst, rations which survive the blast and fire should generally be usable. But after a surface or subsurface burst special precautions will have to be taken against the possibility of radioactive contamination. Unpackaged food which has been in direct contact with the base surge or with the fall-out will be unfit for consumption. However, if there was no actual contact with the food itself, it will be unaffected. The radiations as such can do no harm to food. It is only when the radioactive particles are on the food, and can thus enter the body, that there is real danger. Canned and packaged goods are not affected in any way. Provided contamination, if present, can be washed off the exterior without risk, and the hands are clean, the contents may be safely consumed.

6.90. Potable water supplies, if exposed, may become contaminated, but not necessarily to a dangerous level. However, if stored in closed tanks the water will be safe for consumption. Due care must, of course, be taken to prevent the water from becoming contaminated by subsequent handling.

EFFECTS AT SEA

Damage Ranges for Shock and Blast

6.91. All the information concerning the effects of atomic explosions on ships was obtained from the tests at Bikini, where many of the vessels were of obsolete types, and were, in any case, riding at anchor. From these observations certain conclusions have been drawn concerning what might be expected from modern vessels. While these are often only intelligent guesses, they are worthy of consideration. In the discussion which follows, thermal radiation is not mentioned. The Bikini tests indicated that it would not be an appreciable factor in producing damage at sea, since the exposed portions of naval vessels are practically fireproof. However, this does not exclude the possibility of secondary fires involving such combustibles as gasoline or explosives where there has been extensive blast damage.

6.92. The approximate limiting distances from surface zero at which various degrees of damage may occur to ships and their equipment, from an air burst and a moderately shallow underwater burst, are given in table 6.92. This refers to a nominal atomic bomb. For purposes of comparison with effects of an air burst on land, the distance scale in table 6.92 is in intervals of 500 yards, the same as in table 6.59. A comparison of blast damage at sea and on land, for an air burst, is also given in figure 6.92. Severe damage implies that the ship will be sunk or damaged to such an extent as to completely lose its military effectiveness; moderate damage means immobilization and probable flooding of at least one primary compartment; light damage refers to damage to electronic and other light equipment. It is of interest to note that beyond about 1,500 yards from surface zero only damage of a minor character should be experienced at sea.

6.93. In scaling for the effects of bombs of different energies, the cube-root rule may be used to calculate the damage ranges for an air burst. The various distances in table 6.92 should thus be multiplied by the factor $(W/20)^{1/3}$. For an underwater burst, where the damage is largely due to shock, rather than to blast, this factor would probably underestimate the damage range. If scaling is necessary it would be advisable to use the factor $(W/20)^{1/2}$. The range of appreciable contamination on ships due to the base surge and fall-out following an underwater burst, will be the same as given in paragraph 6.67, that is, about 2 miles crosswind from the center of the explosion and still farther in the downwind direction.

General Effects of Blast and Shock on Ships

6.94. Ships as a whole are remarkably resistant to blast damage. This follows from a consideration of the requirements which must necessarily be built into a seagoing vessel. For example, a considerable portion of the topside area of a combatant ship is built to withstand blast from the firing of its own guns. The hull proper is required to withstand impact of waves, as also are portions of the superstructure. Furthermore, many important stations are protected by armor or splinter shields, which are strongly built.

6.95. The design and materials of construction permit deflection and yielding without rupture. In addition, the ship is floating in water and can yield as a whole (by rolling or heaving) without sustaining any damage due to this motion, whereas a structure of comparable size on land would be damaged by the very act of moving the entire assembly relative to its foundations.

6.96. Orientation and shape of structure will have a considerable influence on damage. Surfaces nearly parallel to the direction of burst will be damaged less than those more nearly perpendicular to it. In some locations not exposed to the direct blast, damage will result from the combined effect of deflection and re-

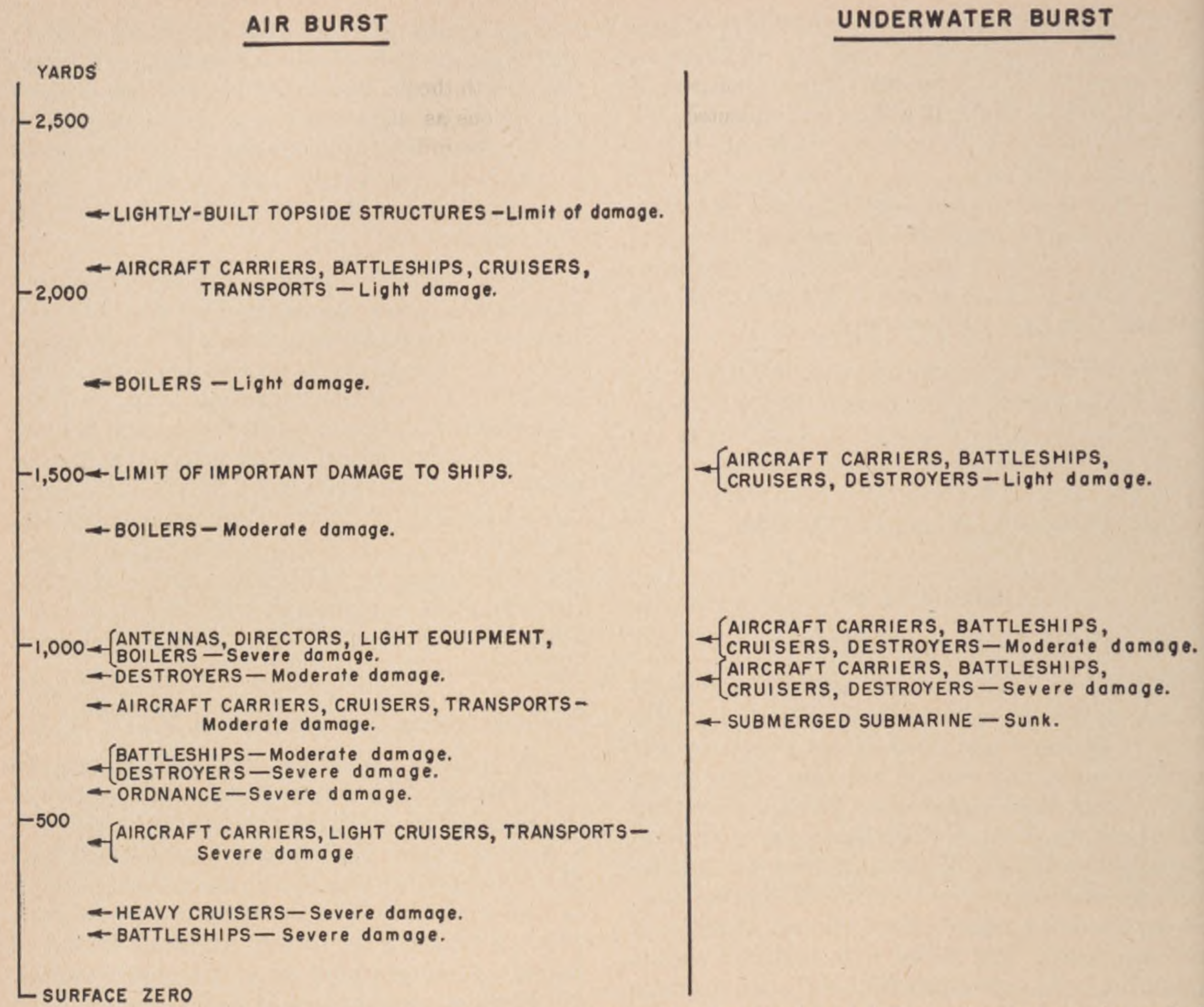


Table 6.92. Comparison of damage ranges to ships, due to air burst at 2,000 feet altitude and shallow underwater burst of a nominal atomic bomb.

flection of the blast wave from exposed surfaces into pockets or dead ends under overhanging structures, gun sponsons, etc.

6.97. On ships having large exposed deck areas, such as the well decks of older type cruisers, quarter-decks of battleships, cargo-handling decks of merchant-type vessels, the decks may be deformed as a result of blast pressure. The main strength water-tight hull will not be affected materially at ranges greater than 600 yards from the explosion of a nominal atomic bomb. This approximate limit applies to both air bursts and underwater bursts. For an underwater burst at ranges up to about 600 yards the underwater shock is sufficient to cause direct rupture of the hulls of most vessels, due to the effects previously discussed in paragraph 6.17. For an air burst, at distances closer than 600 yards the strength hull may be distorted above the water-line sufficiently to initiate cracks which will progress to below the water-line and permit extensive flooding. On light aircraft carriers, warping and buckling of flight decks probably will occur to about 700 yards (fig. 6.97). It is possible that the airplane elevators will be dislodged from their position, and it is still more likely that the distortion of the deck and resulting misalignment will render operation of the elevators impossible.

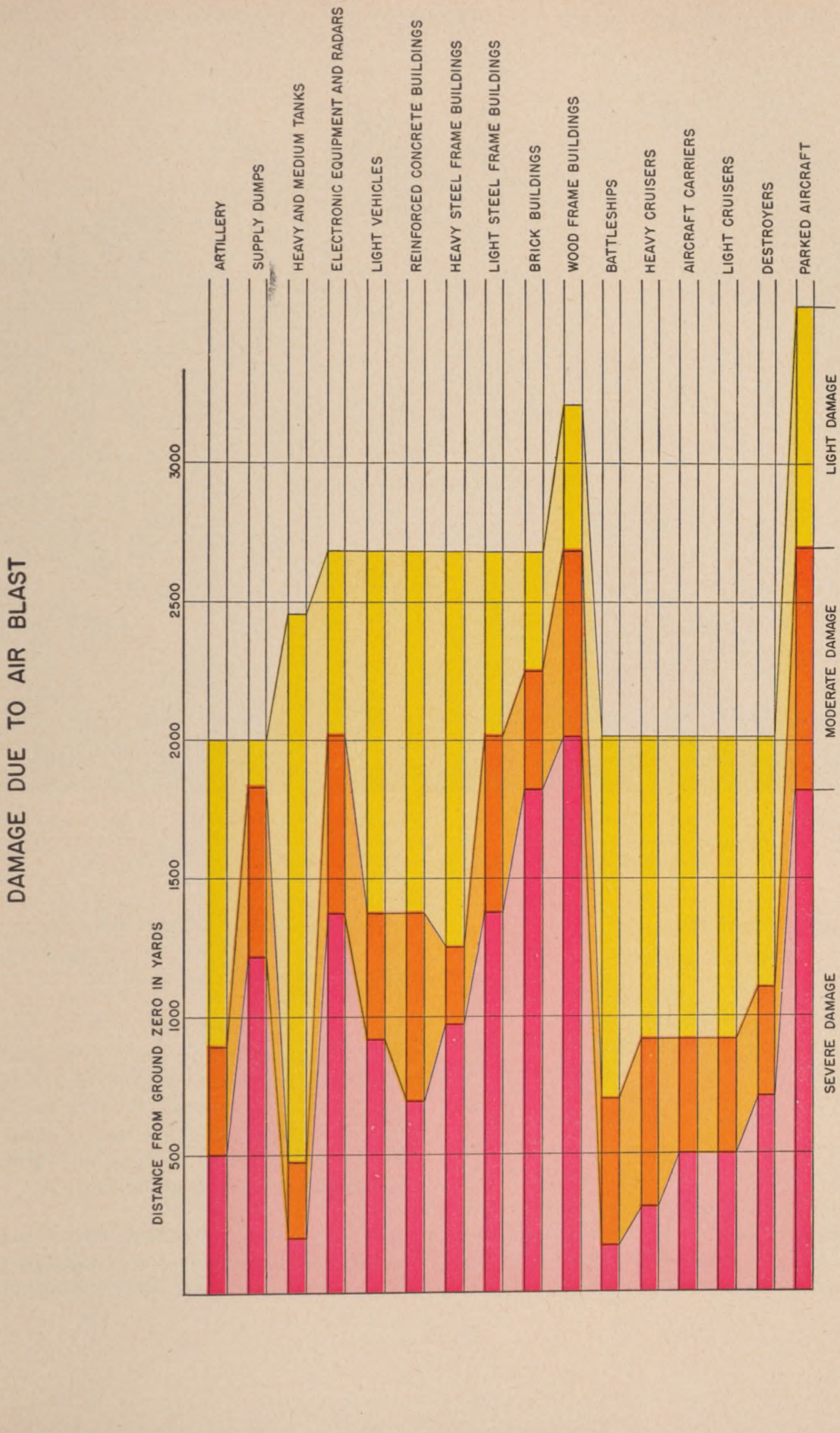


Figure 6.92. Comparison of damage ranges of structures, equipment, ships, and aircraft due to air burst of nominal atomic bomb at 2,000 feet altitude.

NUCLEAR (GAMMA) RADIATION EFFECTS

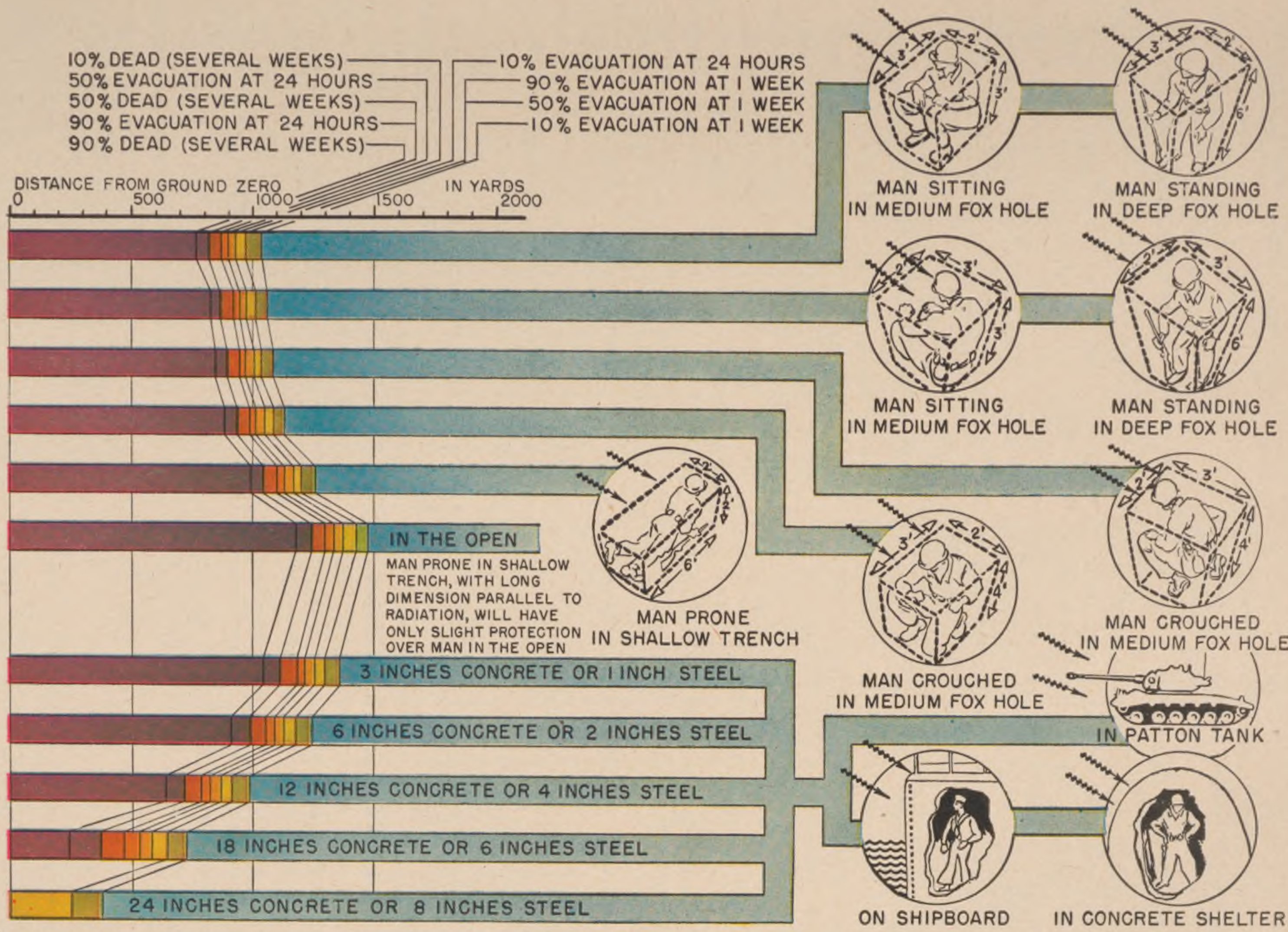


Figure 7.40. Expected casualties due to initial nuclear radiation at various distances from ground zero due to air burst of a nominal atomic bomb at an altitude of 2,000 feet. The influence of various types of shelter is shown. In the case of personnel "in the open," it should be noted that the above casualty ranges would apply only for personnel completely shielded from the thermal radiation (for example, by heavy clothing) since the ranges for possible thermal injury considerably exceed those for nuclear radiation injury. (For similar chart showing effects of thermal radiation, see fig. 7.24.)

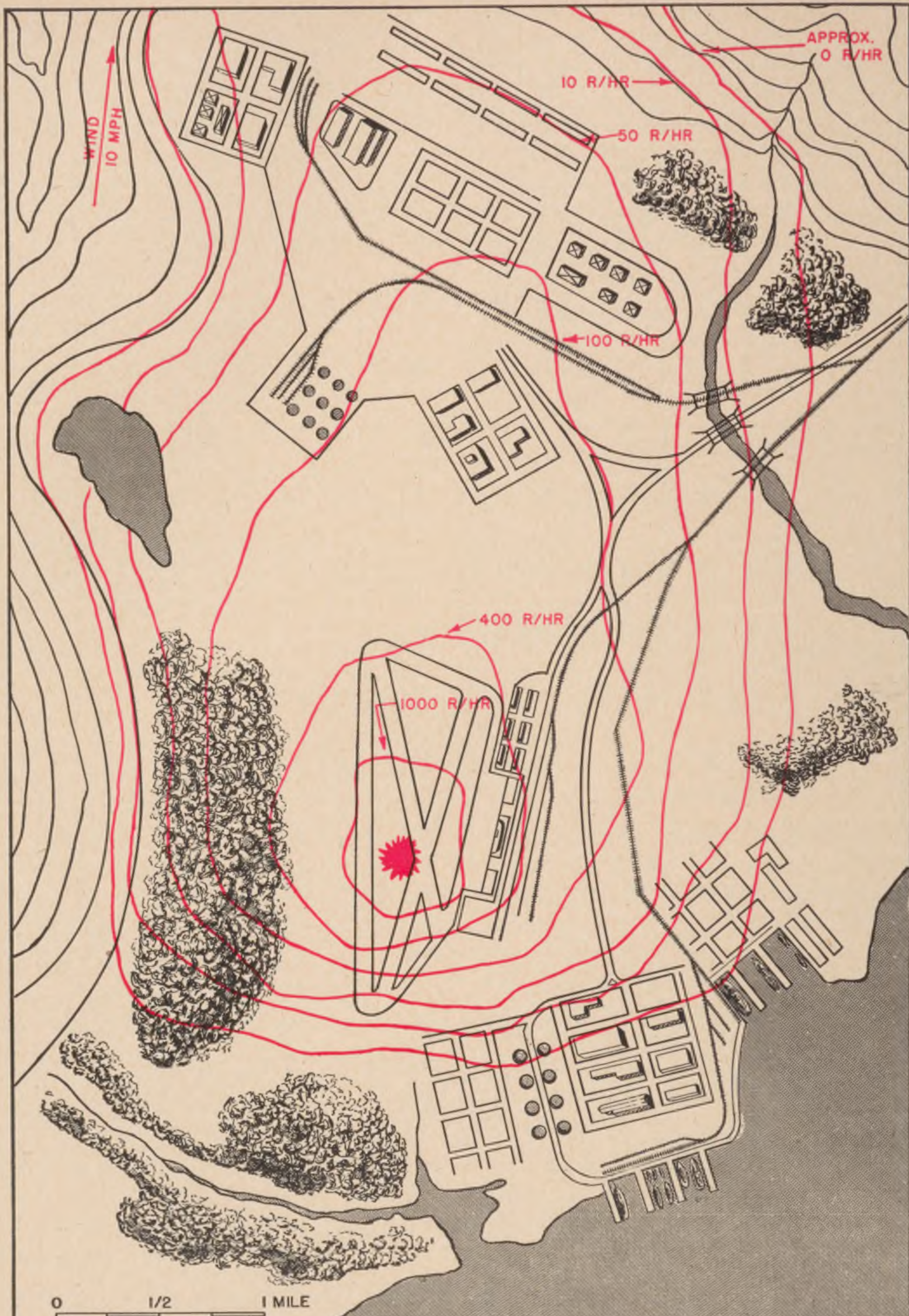


Figure 9.30a. Map of a typical military base in a forward area. Shown in red are contours of equal radiation intensity as they might be plotted at control center, from monitoring data corrected to one hour after detonation. An underground burst, with 10 m.p.h. surface wind, was assumed.

Figure 9.30b. Map of a typical municipal and harbor area. Dose-rate contours show monitoring data corrected to one hour after detonation as in figure 9.30a, except that an underwater burst with 5 m.p.h. wind was assumed.

10.28. Tunnels, storm drains, and subways would provide effective shelter, unless there were a nearby underground explosion. The thickness of the earth will, in general, be sufficient to reduce the gamma radiation to harmless proportions. In addition, the structure of the tunnel, etc., will usually be strong enough to withstand blast and fire, although it may be somewhat vulnerable to underground shock.

10.29. In case of a subsurface explosion, persons taking shelter in existing buildings or structures may become exposed to residual radioactivity from contamination. Closing doors, windows, and other openings will provide some degree of safety. But, if the blast should break the doors and windows, and let in the radioactive mist or dust, this precaution will be of little value. In these circumstances, if no gas masks are available, breathing through a folded handkerchief will help to reduce the hazard.

10.30. In military installations, there often are not many buildings which are strong enough to provide effective shelter from an atomic burst. Culverts, drains, and ditches could be used in the event of an emergency, but they would offer only partial protection. Consideration should, therefore, be given to the desirability of making proper provision for sheltering personnel, in some such manner as is described below.

Shelter Afloat

10.31. Larger ships, and especially those having protective armor, can furnish excellent shelter from blast, thermal radiation, and immediate nuclear radiation effects at one-half mile or more from surface zero in the air burst of a nominal atomic bomb. Such shelter would, of course, be available only to members of the ship's company whose duties will permit them to be stationed behind shielding.

10.32. In general, the further below the main deck, the better will be the protection from nuclear radiation. Shielding is provided by armored decks, the shell plating and side armor, and by the wing water and fuel-oil tanks which form part of the antitorpedo protection. Furthermore, in the case of personnel located well below the water line, the external sea water itself offers valuable shielding against the immediate nuclear radiation. This arises because for even a fairly high air burst occurring one-half mile away, or more, the radiation will strike the ship at such an angle that it must pass through an appreciable thickness of water before entering the ship below the water line.

10.33. In the event of an underwater burst there will be no immediate radiation, but steps should be taken to prevent entry of the base surge. Consequently, all openings should be secured upon warning of an impending attack.

10.34. Unless special shielding is available, topside personnel will be exposed to both thermal and nuclear radiation, as well as to the effects of blast. In case of an air burst, self-preservation measures, to be described later, should be taken. After an underwater explosion, at not too close quarters, there may be time to obtain shelter from the base surge and water fall-out in those cases where it is not possible for the entire ship to avoid this contamination by means of maneuvering.

Specially Constructed Shelters

10.35. For personnel and services of essential importance to the functioning of a military establishment or installation, it may be considered desirable to construct special shelters. These should be built underground of reinforced concrete, perhaps 2 feet thick, and with a considerable earth cover. A structure of this kind would provide satisfactory protection, even at ground zero, from an air burst of a nominal atomic bomb at 2,000 feet. If sufficiently massive and built to withstand lateral shock, the structure could also provide protection from the effects of a nearby underground explosion.

10.36. Two aspects of specially constructed shelters require attention—these are access and air supply. Each shelter should have at least two exits, in case one caves in or is blocked by debris. The entrance passages (or ramps) should be at right angles to the shelter proper, so as to avoid direct exposure to blast, and thermal and nuclear radiations. To prevent the entry of contamination, the shelter should be airtight, except for provision made for supplying air by fans or blowers. An efficient filter should be placed in the inlet duct to remove contaminated dust particles. The Army Chemical Corps No. 6 Filter is suitable for this purpose. Because there may be a power failure in the event of an atomic attack, an emergency supply of electricity should be available to provide lighting and to operate the ventilation system.

10.37. Where shelters are required mainly for protective purposes and not to house vital operational or control activities, much simpler methods can be used. Tunnels cut in a hillside, with entries at right angles to the main tunnel, form very effective shelters. In Nagasaki, such shelters protected persons from blast and from thermal and nuclear radiations very close to ground zero (fig. 10.37).

10.38. If the terrain is flat, several other cheap forms of shelter, which use earth as a protective medium, are possible. In the "cut-and-cover" type, a deep pit or trench is dug, and the sides are shored up with planks and wooden columns. Stout beams are placed across the excavation and upon them are laid sheets of corrugated iron. These are finally covered with a layer of earth at least 3 feet thick. The approach to the shelter is by a right-angled ramp entrance, there being two such entrances to each shelter (figs. 10.38a and b). Digging tools should be available as a further precaution against entrapment by cave-in. A shelter of this kind will provide good protection against all the effects of an air-burst nominal atomic bomb beyond one-half mile or so from ground zero.

10.39. A half-buried shelter, which is partly above and partly under ground, is similar to, but not quite so good as, the type just described. These are very simple to construct. Wood may be used for roofing in place of the corrugated sheets, but it is, of course, less permanent. A baffle of earth and boards at the entrance is desirable, to prevent direct access of blast and radiation. In Japan, half-buried shelters were made of a framework of poles, over which was placed tarpaulins; the whole was then covered with a thick layer of soil (fig. 10.39).

Figure 10.37. Tunnel shelters in hillside, very close to ground zero in Nagasaki, protected the occupants from blast, thermal radiation, and immediate nuclear radiation.

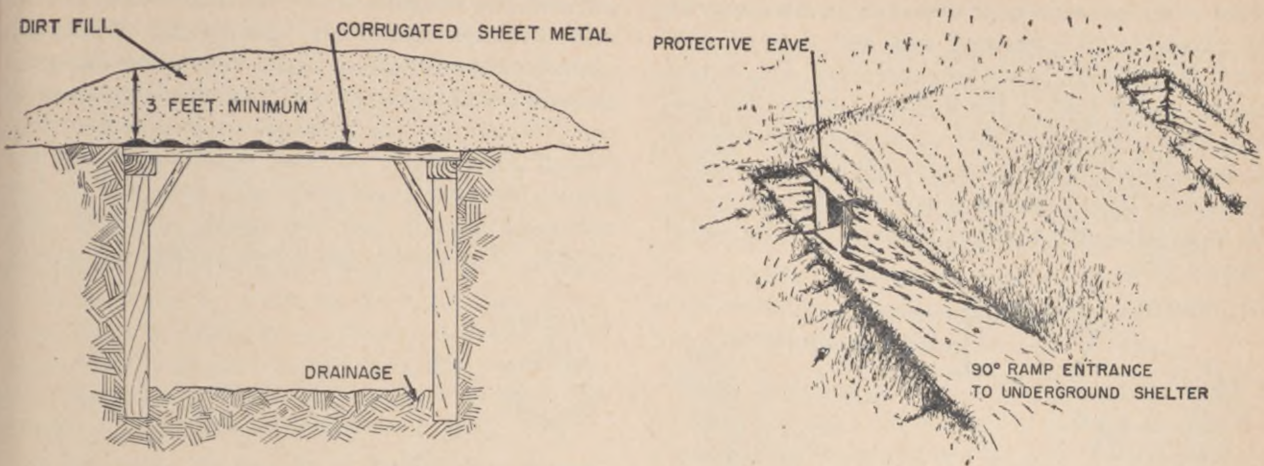


Figure 10.38a & b. Simple earth shelter suitable for a military establishment.

Figure 10.39. Simple pole and earth shelter, one mile from ground zero, undamaged by fire and blast although surrounding buildings were destroyed in the atomic bombing of Japan. (Debris was cleared from the roadways before the photograph was taken.)

10.40. In a more elaborate, and more expensive, form of the cut-and-cover shelter, a quonset hut can be placed in an excavated area and covered with earth (fig. 10.40a). Two ramp entrances, dug at right angles, would lead to the doors. A somewhat similar shelter could be made from steel culvert sections of large diameter, which are obtainable commercially. Several sections could be joined together, placed in an excavation, and an appropriate earth cover added (fig. 10.40b).

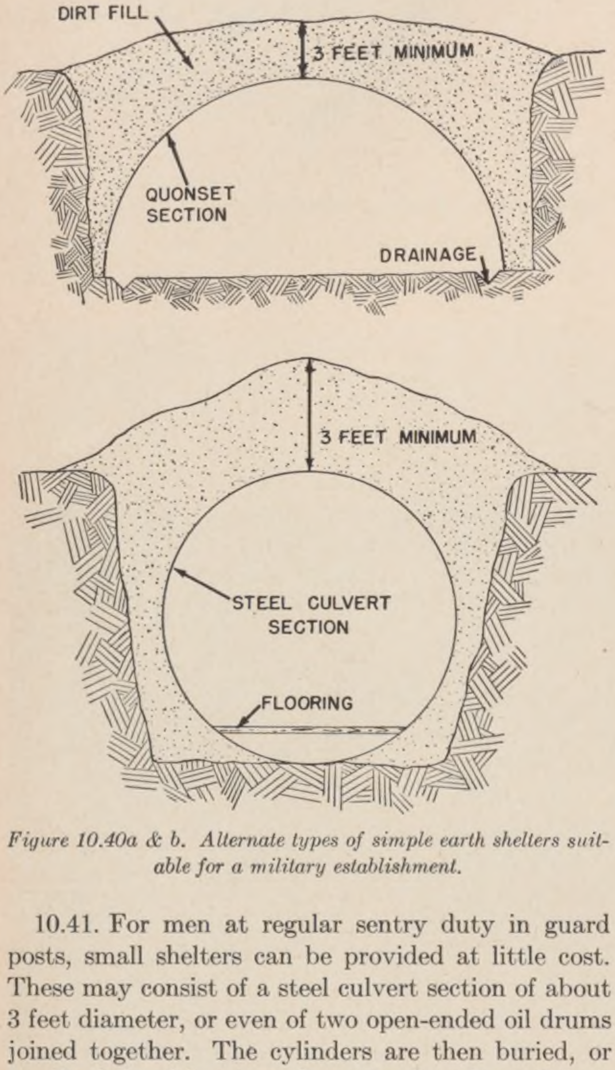


Figure 10.40a & b. Alternate types of simple earth shelters suitable for a military establishment.

10.41. For men at regular sentry duty in guard posts, small shelters can be provided at little cost. These may consist of a steel culvert section of about 3 feet diameter, or even of two open-ended oil drums joined together. The cylinders are then buried, or semiburied, with an earth cover of at least 3 feet. A ramp entrance must be provided for the completely buried shelter. One or two men lying down inside will be well protected beyond about one-half mile from ground zero in the event of an air burst.

10.42. Slit trenches and foxholes (see fig. 7.40) provide the simplest of all shelters which can be made available at military installations. Where the number of personnel is large, then more elaborate shelters are not practicable. The chief drawback to trenches and foxholes is, of course, their lack of protection from above. A high air burst at not too great a distance would send blast, heat, and nuclear radiations directly into the trench or foxhole (fig. 10.42a). The deeper the trench is dug, the greater

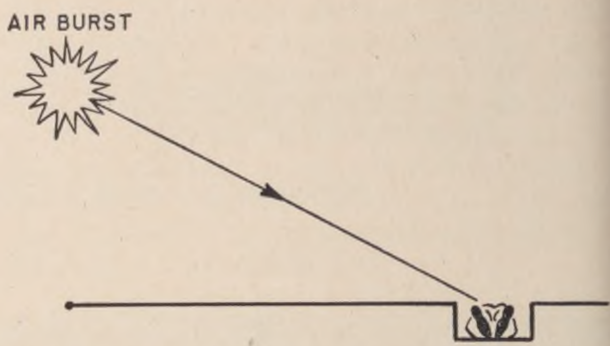


Figure 10.42a. A high air burst sends radiations (thermal and nuclear) into a small foxhole.

the protection it offers. A soldier lying, sitting, or crouching at the bottom of a deep trench can escape most of the air burst bomb's effects, even quite close to ground zero (fig. 10.42b). Trenches and foxholes would, however, be damaged by shock from nearby surface and subsurface bursts.

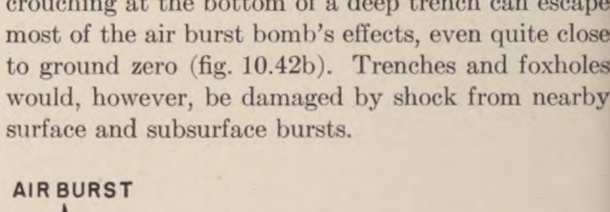


Figure 10.42b. A soldier crouching on the bottom of a moderately deep trench or foxhole is largely protected from the effects of radiation, even fairly close to ground zero. Some scattered nuclear radiation (dotted lines) may be received, but the amount will be comparatively very small.

10.43. A warning should be given in connection with the use of sandbags in the construction of earth shelters. If sufficiently close to the explosion, the burlap or other materials are likely to be scorched by the thermal radiation. The bag may then collapse and its contents will be spilled.

10.44. All the simple types of earth shelter suffer from the fact that they cannot be made airtight. It would thus be impossible to keep out radioactive contamination due to a subsurface burst. The only satisfactory way to overcome the immediate effect of this hazard would be to supply each individual with a filter mask or respirator. If this is not possible, then dust may be largely kept out by breathing through a handkerchief or a piece of cloth.

10.45. It may be possible in the field to take advantage of the terrain. A hill between an individual and the exploding bomb will almost completely cut off the thermal radiation. Although it may not entirely eliminate the effects of blast and the immediate nuclear radiation, it may well reduce them to such an extent that they are harmless.

Dispersion

10.46. An important way in which casualties in the field might be reduced is by dispersion of personnel over a large area. The figures in table 10.46 show the estimated percentages of personnel injured and killed in the open as a result of the air burst of a nominal atomic bomb, assuming them to be concentrated in circular areas of various radii about ground zero. Dispersal of troops over a large area will thus appreciably decrease the number of casualties. The data in table 10.46 are based on the assumption that the troops are in the open at the time of the explosion.[3]

Table 10.46. Estimated Effects of Dispersion of Personnel in the Open

Circular area of radius (yards)	Percent casualties		
	Killed	Injured	Total
1,500	90	10	100
2,000	51	29	80
2,500	33	36	69
3,000	23	40	63
4,000	14	28	42

[3]It should be noted that the casualty ranges given in table 10.46 are based primarily on thermal rather than nuclear radiation effects, since the limiting distance for radiation casualties would be about 1500 yards. On the other hand, if personnel are in foxholes or trenches and thereby shielded from thermal radiation, nuclear radiation becomes more significant in determining the amount of dispersion required to avoid excessive casualties (see figs. 7.24 and 7.40).

10.47. Commanders should consequently give careful consideration to the possibility of distributing personnel, and especially key personnel, as widely as possible (see par. 12.09). All operating procedures should be examined closely to determine whether unnecessarily large numbers of personnel are being concentrated in small areas during these operations. For example, dispersal of aircraft at an air base might reduce casualties to maintenance crews as well as to the planes.

10.48. Dispersal of ships, both at sea and in port, will decrease the total amount of damage and hence the casualties in an atomic explosion. Consideration should consequently be given to the matter of increasing the operating distance between ships when an attack is expected. Because of the great range of destruction resulting from an atomic burst, somewhat different defense tactics are required than in the case of HE bombs and depth charges.

Smoke Screen

10.49. If large numbers of personnel have to remain in the open and cannot take shelter, for example, in an amphibious landing, it might be desirable to employ a smoke screen as a protective device. As stated in paragraph 3.41, this would very greatly reduce the range of thermal radiation and consequently decrease the number of flash-burn injuries. On the other hand, protection from thermal radiation is so relatively simple that it is questionable whether a smoke screen would be justifiable, except in special circumstances, as indicated above. The effective use of a smoke screen is only possible if there is adequate warning of an attack. In any case, it must not be permitted to distract attention from the necessity for obtaining protection from blast and nuclear radiation effects.

INDIVIDUAL PROTECTION

Self-preservation

10.50. If there is a sufficient warning in advance of an atomic attack, the obvious step is to make for the best shelter that is available, as quickly as possible. In the case of members of the armed forces on duty, their behavior must be determined by the circumstances existing at the time. In general, this will be the same as those prescribed for an attack by ordinary HE bombs.

10.51. In the event of a surprise atomic explosion, certain actions can be taken by individuals which might mean escape from death or serious injury. The same applies to men on duty who cannot leave their posts. In an air burst the actions are determined by the following facts mentioned earlier in this manual. First, the thermal radiation may continue to be emitted for a second or so after the burst; second, about 50 percent of the immediate nuclear radiation is given off in the first second, and about 80 percent within 10 seconds; and third, the blast wave takes about 8 seconds to reach a distance of 2 miles, which is the approximate range of serious to moderate mechanical injury.

10.52. The first indication of an unexpected atomic air burst may be a brilliant flash of light. No matter whether in the open or inside a building, the immediate reaction should be for the person to drop to the ground, face down, at the same time trying to cover exposed portions of the skin, such as the face, neck, and hands. If this can be done within a second of seeing the bright light, some of the heat radiation may be avoided. Ducking under a table, if indoors, or into a trench or ditch, if possible, outdoors, with the face away from the light, will provide added protection.

10.53. If shelter of some kind can be reached within a second, it might be possible to miss about half of the immediate nuclear radiation. But, as stated earlier, 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 terrain and surrounding structures. However, since the radiations continue to reach the earth from the atomic cloud as it rises, the protection will be only partial.

10.54. The prone position taken immediately upon seeing the light from the bomb should be held for at least 10 seconds, or longer if heavy objects are still falling. This will allow time for the blast wave to pass and thus decrease the danger from flying missiles. At a distance of 2 miles from the point of burst, 8 seconds will elapse before the sound of the explosion is heard. By this time the immediate effects will be over.

10.55. The light from a subsurface atomic explosion will not be visible for any appreciable distance, especially in the daytime. The first indication of such a burst will probably be the sensation of an earthquake-like concussion of the ground, together with the appearance of the column of water or earth. Fortunately, the thermal and nuclear radiations emitted at the time of the explosion will be absorbed by the water or the earth, respectively. However, there may still be the radiation hazard from the base surge and the fall-out.

10.56. Although the effects of blast and shock may be felt before it is fully realized that a subsurface explosion has occurred, there may still be time to obtain some shelter from the base surge and fall-out. It should be remembered that the base surge is like a fog and envelopes everything over which it passes. Adequate shelter can thus be obtained only in a closed space which the radioactive fog cannot penetrate. The fall-out, on the other hand, descends vertically (or almost so) and protection is much easier to obtain. If it is impossible to find shelter from both base surge and fall-out in a short time, then protection from the fall-out, at least, should be sought. If a filter mask is not available, a handkerchief should be held over the mouth and nose while the base surge is passing.

10.57. After a contaminating burst or an RW attack every action should be taken with the thought of minimizing the spread of the contamination. Within the contaminated area, eating, drinking, smoking, chewing gum, or any action which requires putting the hand to the mouth, must be strictly forbidden. This will help prevent entry of radioactive particles into the body. Personnel should be warned against stirring up dust and stepping into puddles. Brushing against shrubbery and trees or touching buildings and objects in the contaminated area must be avoided. These instructions should be stressed to counteract the temptation to pick up souvenirs.

10.58. The internal radiation hazard due to inhalation of radioactive particles is even greater than that due to ingestion. Realistic evaluation of the dust hazard by laboratory analyses should be made as soon as feasible. If found serious, shelter from dust clouds raised by the wind, by aircraft propellers, by moving vehicles, etc., should be taken, if possible. Otherwise a gas mask, or handkerchief, should be used, as described above, for protection. In the case of aircraft in flight, if there is reason to believe that the plane may be in the vicinity of an atomic cloud, protection for the crew can be obtained by shutting off the ventilation or pressurization system. Further individual protection can be obtained by the use of the oxygen masks.

First Aid

10.59. As soon as the initial effects of the explosion are over, every survivor should look around to see if he can render first aid or emergency help of any kind to individuals nearby (see ch. 7). It is important to emphasize that after an air burst the administration of such help involves no special problems. The situation from this standpoint will be no different from that following an HE or incendiary attack. As indicated in paragraph 7.39, there is no danger involved in approaching or touching a person who may have received a dose of immediate nuclear radiation from an air burst.

10.60. Persons with wounds, which might permit radioactive material to enter the body, should be taken to the nearest medical station for treatment. Regardless of the indicated extent of the contamination, amputation is entirely unnecessary, in spite of statements which occasionally have been made to the contrary.

PROTECTIVE CLOTHING AND EQUIPMENT

Ordinary Clothing

10.61. Military uniforms and civilian clothing provide good protection against thermal radiation emitted at the time of an air burst. The protection is, however, supplementary rather than primary, in nature. If a person is beyond the zone of serious damage from blast and nuclear radiation, he may still be vulnerable to thermal radiation, since this has the greatest damage range. In these circumstances parts of the body that are covered by clothing will be fairly well protected from flash burns. As far as radiological effects are concerned, the chief protective value of clothing is that it keeps radioactive contamination from actual contact with the skin.

Special Clothing and Equipment

10.62. Personnel whose duties, as members of emergency and damage control teams, as decontamination crews, or as monitors, require them to enter contaminated areas or to come into contact with contaminated objects, should wear special clothing when available (fig. 10.62).[4] Such clothing normally would be issued from a control point or change station. It should be washable or expendable, and should be tightly woven or nonporous. It should cover the body completely, and should have tight connections with gloves at the wrists, and with shoes at the ankles. An overlapping connection should also exist between the clothing at the neck and a respirator or filter mask. Equipment of this kind will prevent contamination of the skin.

10.63. After each use, the clothing should be monitored.[5] Most contaminated clothing can be laundered and used again (par. 10.82). An alternative to laundering or disposal is to store the clothing to permit the radioactivity to decay. The soiled clothing is set apart in special containers and allowed to stand until its contamination has decayed sufficiently for it to be worn again.

10.64. The special clothing which should be used, if available, by personnel entering contaminated areas, can be itemized as follows:

- Any type of head covering, preferably tight-fitting.
- Goggles.
- Suitable washable and/or disposable outer garments.
- Bootees.
- Gloves, canvas type for manual labor.
- Filter masks.

10.65. Because of the possible confusion following an atomic attack, the special clothing may not be immediately available; satisfactory substitutes may be improvised as follows:

- Standard military clothing or combat fatigues.
- Clothing tightly buttoned at neck and tied at wrists and ankles with string, or stuffed into top of combat boots.

---

[4] This is sometimes referred to as "protective" clothing, although it offers virtually no protection from gamma radiation. The term "protective" may consequently be misleading in this respect.

[5] Further discussion of the monitoring of clothing will be found in the Department of Defense "*Handbook of Atomic Weapons for Medical Officers.*"

SCALING LAWS FOR ESTIMATING BLAST, THERMAL, AND IMMEDIATE NUCLEAR RADIATION EFFECTS FOR ATOMIC BOMBS OF DIFFERENT ENERGIES

A.1. A number of figures are appended here which will permit fairly accurate scaling estimates to be made rapidly. They give the peak overpressure on the ground due to an air burst (fig. A.1a), the thermal energy received (fig. A.1b), and the immediate nuclear (gamma) radiation dose (fig. A.1c), respec-

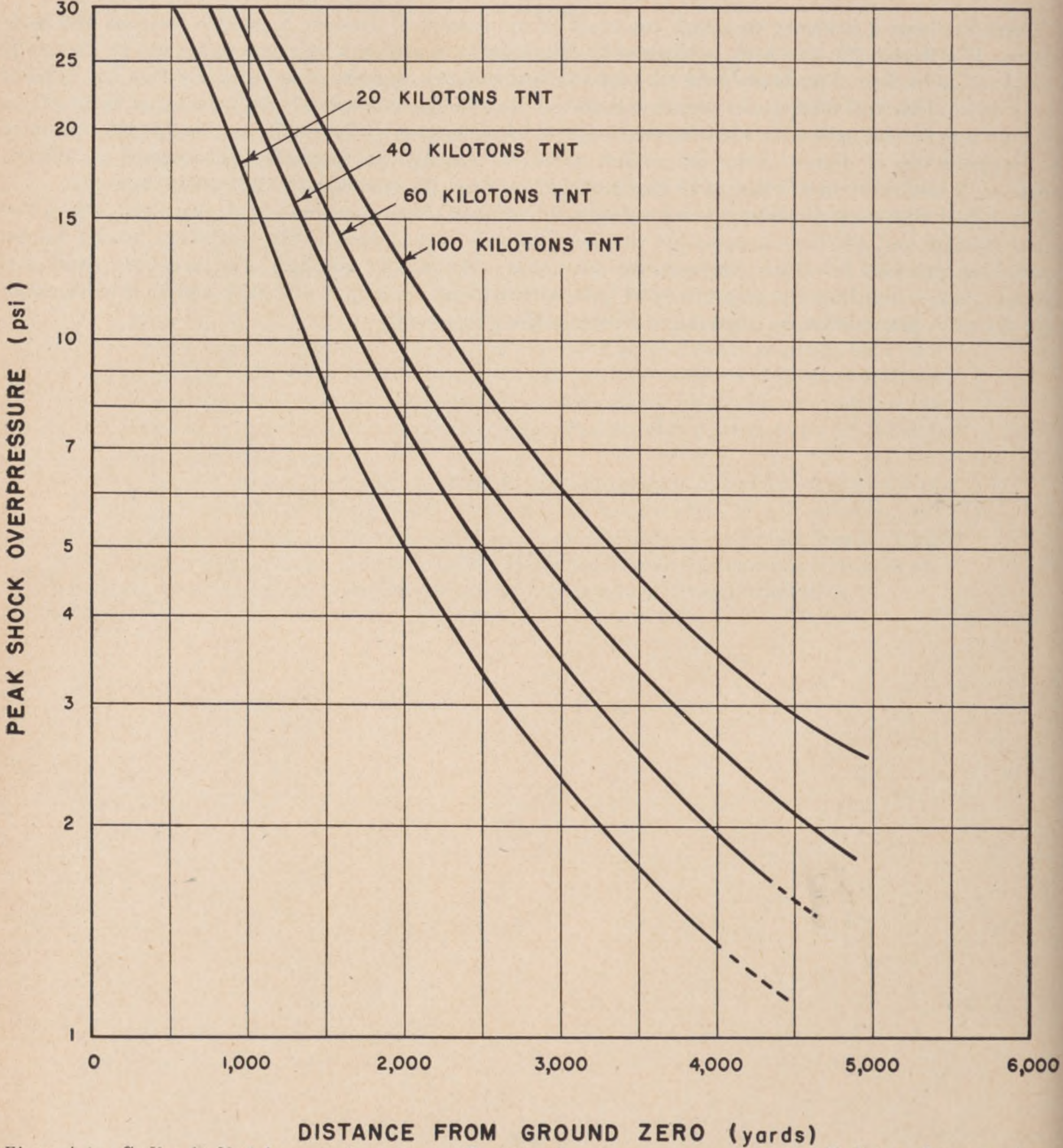


Figure A.1a. Scaling for blast from atomic air bursts. Variation of peak overpressure on ground with distance from ground zero.

tively, at various distances from ground zero, for bombs of different energies. It should be noted that in figure A.1b, the ordinates are thermal energies, in calories per sq. cm., divided by the kiloton TNT energy equivalent of the bomb, i. e., the thermal energy per kiloton TNT of bomb energy. To obtain the results for a bomb of energy equivalent to W kilotons TNT, the ordinates are multiplied by W.

Example: What would be (i) the peak overpressure; (ii) the thermal energy on an average clear day; and (iii) the immediate nuclear radiation dossage, at a point 2,000 yards from ground zero, due to the air burst of a 60-kiloton TNT equivalent atomic bomb?

(i) From figure A.la, using the curve marked "60 kilotons TNT," the peak overpressure at 2,000 yards is seen to be about 9.5 psi.

(ii) The thermal energies received on an average clear day may be regarded as being roughly mid–

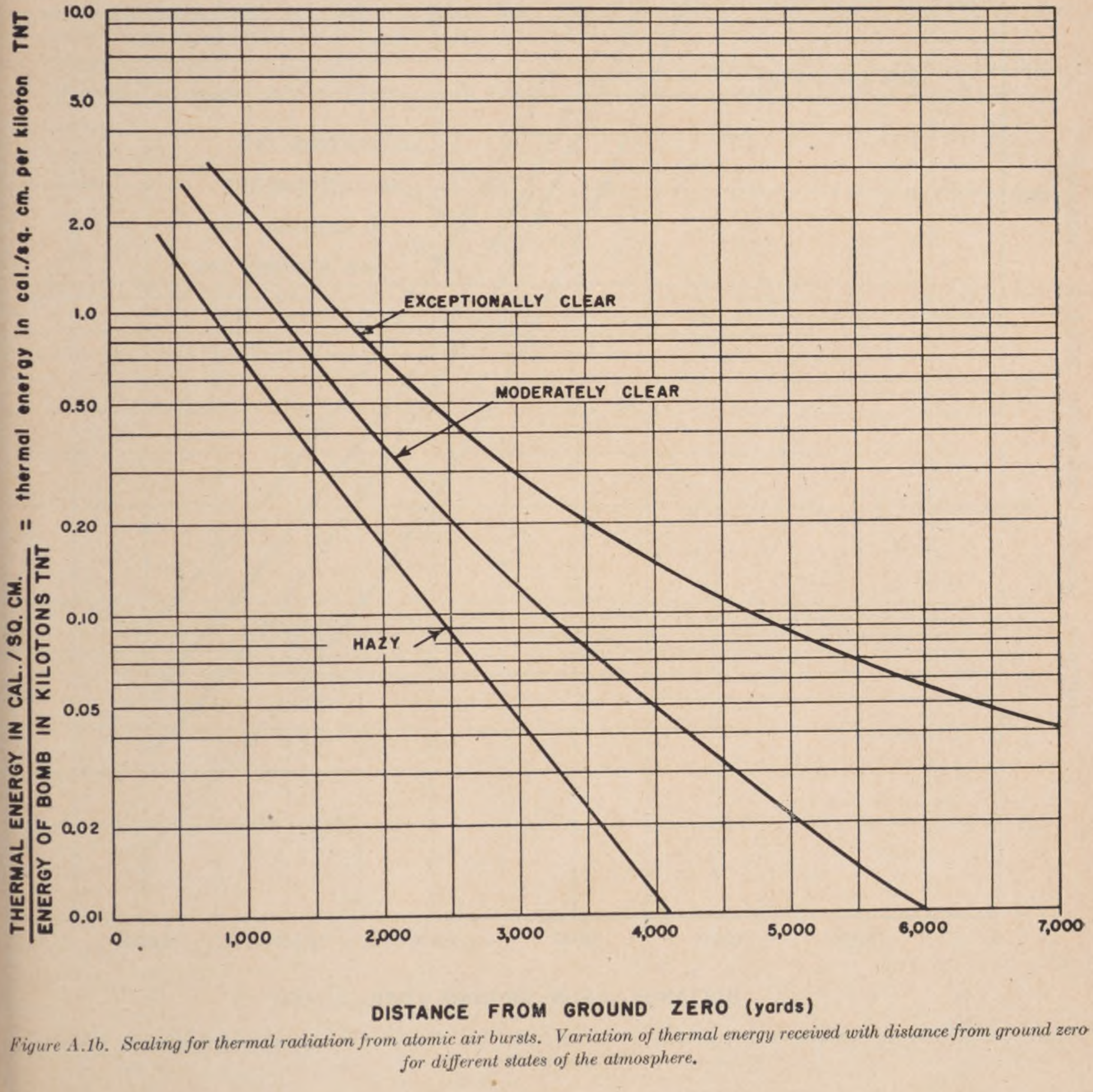


Figure A.1b. Scaling for thermal radiation from atomic air bursts. Variation of thermal energy received with distance from ground zero for different states of the atmosphere.

way between those for the curves marked "moderately clear" and "exceptionally clear." The ordinate of figure A.1b corresponding to a distance of 2,000 yards, is thus found to be about 0.5 cal./sq. cm. Upon multiplying by 60, which is the kiloton TNT equivalent of the bomb, the result is 30 cal./sq. cm. as the energy received.

(iii) From figure A.1c, using the curve marked "60 kilotons TNT," the immediate nuclear radiation dose at 2,000 yards is seen to be 66 roentgens.

Example: What is the limiting distance from ground zero at which moderate skin burns would be experienced on an average clear day as the result of the air burst of a 30-kiloton TNT equivalent bomb?

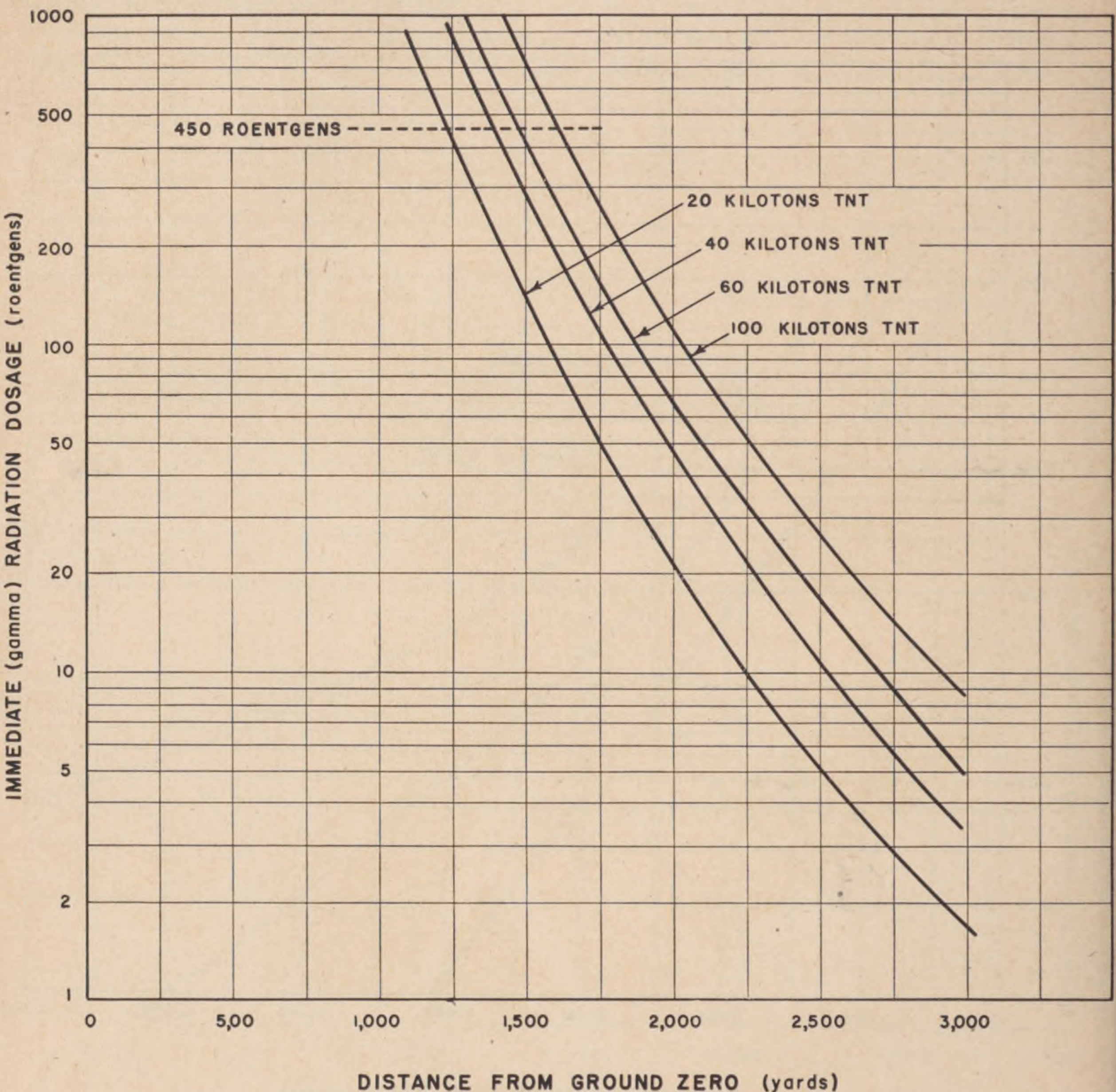


Figure A.1c. Scaling for immediate nuclear radiation from atomic air burst. Variation of total radiation dosage with distance from ground zero.

The thermal energy required to produce moderate skin burns is 3 cal./sq. cm., and this divided by 30, the kiloton TNT equivalent of the bomb, is 0.1. The ordinate 0.1 in figure A.1b for an average clear day, i. e., between "moderately clear" and "exceptionally clear," corresponds to a distance of 3,750 yards from ground zero. This is the required limiting distance.

A.2. Some of the scaling data have been plotted in a simpler manner in figure A.2. While this is less complete than the figures given above, it is simpler to use. It should be noted that the thermal radiation curves refer to an average clear day.

Example: At what distance from ground zero would the air burst of a 100-kiloton TNT equivalent bomb produce (i) a peak overpressure of 5 psi on the ground; (ii) 3 cal./sq. cm. of thermal radiation on a clear day; (iii) 450 roentgens of immediate nuclear radiation?

(i) The estimated distance for 5 psi, obtained by interpolation between the curves "3 psi" and "10 psi," is about 3,500 yards, for a 100-kiloton TNT bomb.

(ii) From the curve for "3 cal./sq. cm." of thermal radiation, the distance is found to be about 6,000 yards.

(iii) The curve "450 roentgens" indicates that the distance would be approximately 1,650 yards.

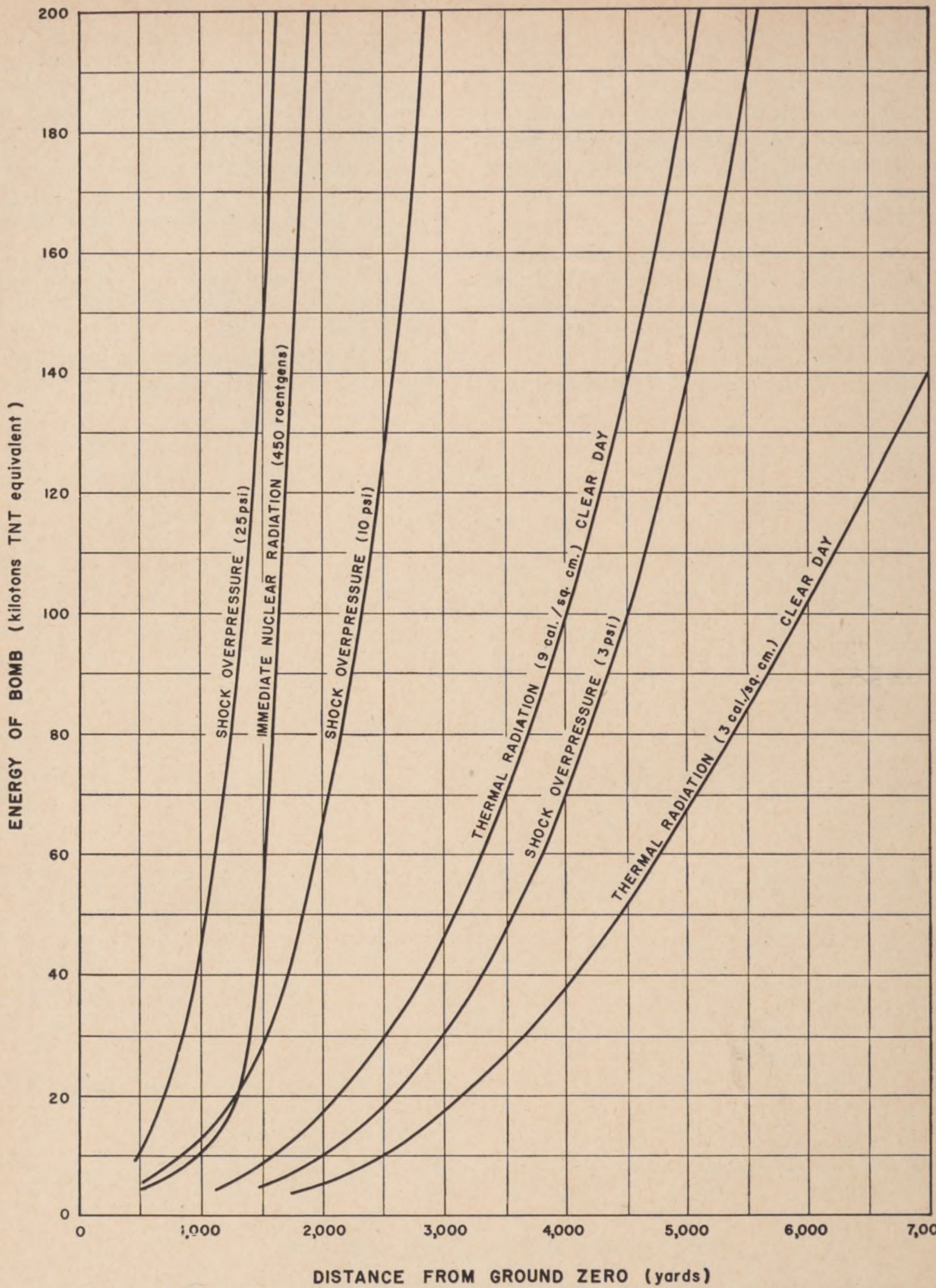


Figure A.2. Distances from ground zero at which various effects are produced by the air burst of atomic bombs of different energies.