FEMA 130/ June 1987
(Supersedes CPG 2-1A6 dated June 1973, which may not be used.)

ATTACK ENVIRONMENT MANUAL

Chapter 6

What the planner needs to know about Fallout

FEDERAL EMERGENCY
MANAGEMENT AGENCY

FOREWORD

WHAT THE EMERGENCY PLANNER NEEDS TO KNOW ABOUT THE NATURE OF NUCLEAR WAR

No one has gone through a nuclear war. This means there isn't any practical experience upon which to build. However, emergency management officials are responsible for preparing for the possibility of nuclear war. Intelligent preparations should be based on a good understanding of what operating conditions may be like in a war that has never occurred. If the planner lacks such understanding, the emergency operations plans produced probably won't make sense if they ever have to be used.

The Attack Environment Manual has been prepared to help the emergency planner understand what such a war could be like. It contains information gathered from over four decades of study of the effects of nuclear weapons and the feasibility of nuclear defense actions, numerous operational studies and exercises, nuclear tests experience, and limited experience in wartime and peacetime disasters that approximate some of the operating situations that may be experienced in a nuclear attack. In short, it summarizes what is known about the nuclear attack environment as it could affect operational readiness at the local level.

The data on the effects of nuclear weapons used in this manual have been taken from the 1977 edition of "The Effects of Nuclear Weapons" (ENW), compiled and edited by S. Glasstone and P. J. Dolan and prepared and published by the United States Department of Defense and the United States Department of Energy. Copies are available for purchase from the U.S. Government Printing Office. The ENW is the most widely available authoritative source of weapon effects and is in many public libraries across the country. For these reasons it was chosen as the source data in this manual.

This Attack Environment Manual supersedes CPG 2-1A1 through 2-1A9.

PREFACE TO CHAPTER 6

The phenomenon known as "fallout" came into being in 1945 with the detonation of the first "atomic bomb" in New Mexico, July 16, 1945. Fallout received world wide attention after the March 1, 1954, test BRAVO, a 15 MT thermonuclear device detonated at Bikini Atoll. Fallout is the process of the descent to the earth's surface of particles contaminated by fission products from the radioactive cloud. The term is also applied to the contaminated particulate matter itself. The radiation emitted by these particulates is called fallout radiation. Early (or local) fallout is conventionally defined as that which reaches the earth's surface within 24 hours. Delayed (or worldwide) fallout consists of finer particles from the upper troposphere and the stratosphere and are spread by winds across the globe. Its descent extends over months and years.

The chapter begins with introductory materials to acquaint the reader with the phenomenon and the basic aspects of radioactivity in fallout. It then summarizes the basis for predicting early fallout from surface-burst weapons. Six panels follow on what would be observed by the eye and with radiation detection instruments in the area affected by early fallout. The next topics treated are shielding from fallout radiation and changes expected due to differing winds and weapon sizes. Another major section is devoted to contact and internal hazards of fallout radiation and its effects on animals and plants. The special problems of urgent emergency operations in damaged areas where fallout is present also are discussed. Finally, a section is devoted to some common questions about fallout. The chapter concludes with a list of references and suggested additional reading for those who are interested in further or more detailed information.

LIST OF CHAPTER TITLES

*Chapter 3 will be published at a later date.

CONTENTS OF CHAPTER 6

WHAT THE PLANNER NEEDS TO KNOW ABOUT FALLOUT

RADIOACTIVITY IN FALLOUT

Nuclear radiation is a major effect that is unique to nuclear weapons. The other effects differ from conventional weapons only in degree. Some aspects of the effects of ionizing radiation were considered in chapter 5. In a real sense, however, it is the residual radiation or fallout from nuclear weapons that poses special problems that make civil defense today quite a different thing from the civil defense of World War II.

About half the energy produced in the detonation of megaton-yield nuclear weapons results from nuclear fission, a process in which radioactive substances (fission products) are produced. When detonations occur on or near the earth's surface, these fission products plus unfissioned bomb material and materials made radioactive by neutrons are incorporated into the materials scoured from the crater. Much of this debris is carried high into the atmosphere by the rising fireball. The subsequent fall of the debris particulates (pulverized earth, concrete, and the like) has been called "fallout."

In chapter 1, it was noted that the fallout from a single surface burst nuclear weapon could produce hazardous radiation exposures several hundred miles downwind of the detonation point. This threat was demonstrated dramatically in 1954 when fallout from a test explosion more than a hundred miles away caused injuries among the crew of a Japanese fishing boat and among natives on Rongelap Atoll. The quotation shown here indicates the effect that this incident had on planning in the mid-1950's.

At first, very little was known about the potential hazard from fallout. Research since that time has reduced some of the uncertainties involved. But many of the older ideas and assumptions still persist as misconceptions. In this chapter, these misconceptions are dealt with. An attempt is made to present a rather complex subject in simple terms. Even when all useful simplifications are made, the information needed for emergency planning is complex, especially since few are expert in nuclear physics and radiobiology.

The first part of this chapter emphasizes the fallout problems in areas distant from nuclear detonations. Then, the effects of fallout will be described in the area of blast and fire discussed in earlier chapters.

"The advent of the thermonuclear weapon, with its terrifically augmented power of destruction and dangerous fallout, capable of reaching hundreds of miles from a target area, brought virtually the entire country into the civil defense picture and called for wholesale revision of Federal, State and local civil defense planning. The year 1955 was mainly given to this task."

<u>1955 Federal Civil Defense Administration</u>
<u>Annual Report</u>

KINDS OF NUCLEAR RADIATION

At the time of a nuclear detonation, over 300 different radioactive substances are formed by fission. Additional ones are created by neutron irradiation of weapon parts, soil, and other close-by materials. These "fission products" and the "induced activities" are potentially harmful because they emit two kinds of nuclear radiation--beta particles and gamma rays. Some emit only beta particles, but most emit both.

The nature of gamma rays was introduced in chapter 5. Gamma radiation is electromagnetic radiation like light, radio waves, and X-rays. As such, it travels with the speed of light and spends its energy through interactions with the atoms that make up the atmosphere, materials, structures, or human bodies. Gamma radiation has an effective range in air of many hundreds of feet. It takes a considerable thickness of a heavy material, such as concrete or lead, to stop this radiation.

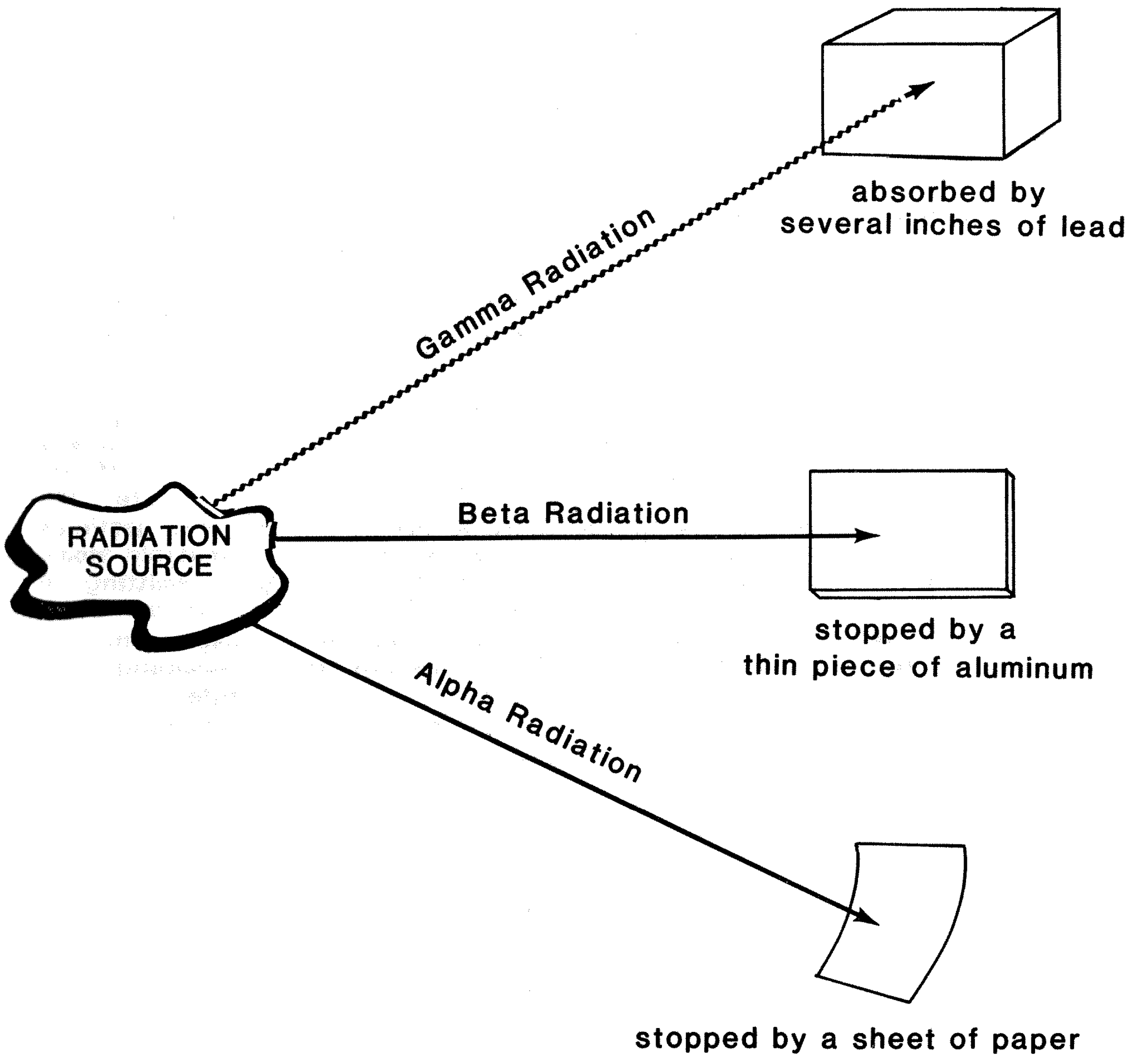
Beta particles are charged particles emitted from the nucleus of a radioactive atom, with a mass and charge equal to that of an electron. Thus, beta radiation is a stream of beta particles. Although traveling initially at nearly the speed of light, beta radiation is much less penetrating than gamma radiation. The beta particle's energy is expended in air in a few millionths of a second within a distance of about 10 feet from its source. A thin piece of aluminum or heavy clothing stops beta radiation.

It is perhaps unfortunate that nuclear physicists have called beta radiation "particles" to distinguish it from electromagnetic radiation. While beta particles are discrete bits of matter, this designation has given rise to the misconception that "beta particles" are granules of sensible size and permanence that could be "swallowed" or "brushed off." These radiations cannot be detected by the human senses and should not be confused with the fallout "particles" containing the radioactive material that emits them.

There is a third type of nuclear radiation shown on this chart--alpha radiation. Alpha particles are emitted by the leftover fissionable material--uranium or plutonium--not used up in the fission process. The amount of leftover fissionable material is inconsequential and the alpha hazard will not be discussed further. Only in the immediate neighborhood of an accident involving the breakup of a nuclear weapon would this type of radiation be of significance. Nuclear defense planning may be undertaken as if it did not exist.

PANEL 2

NUCLEAR RADIATION



RADIOACTIVE DECAY

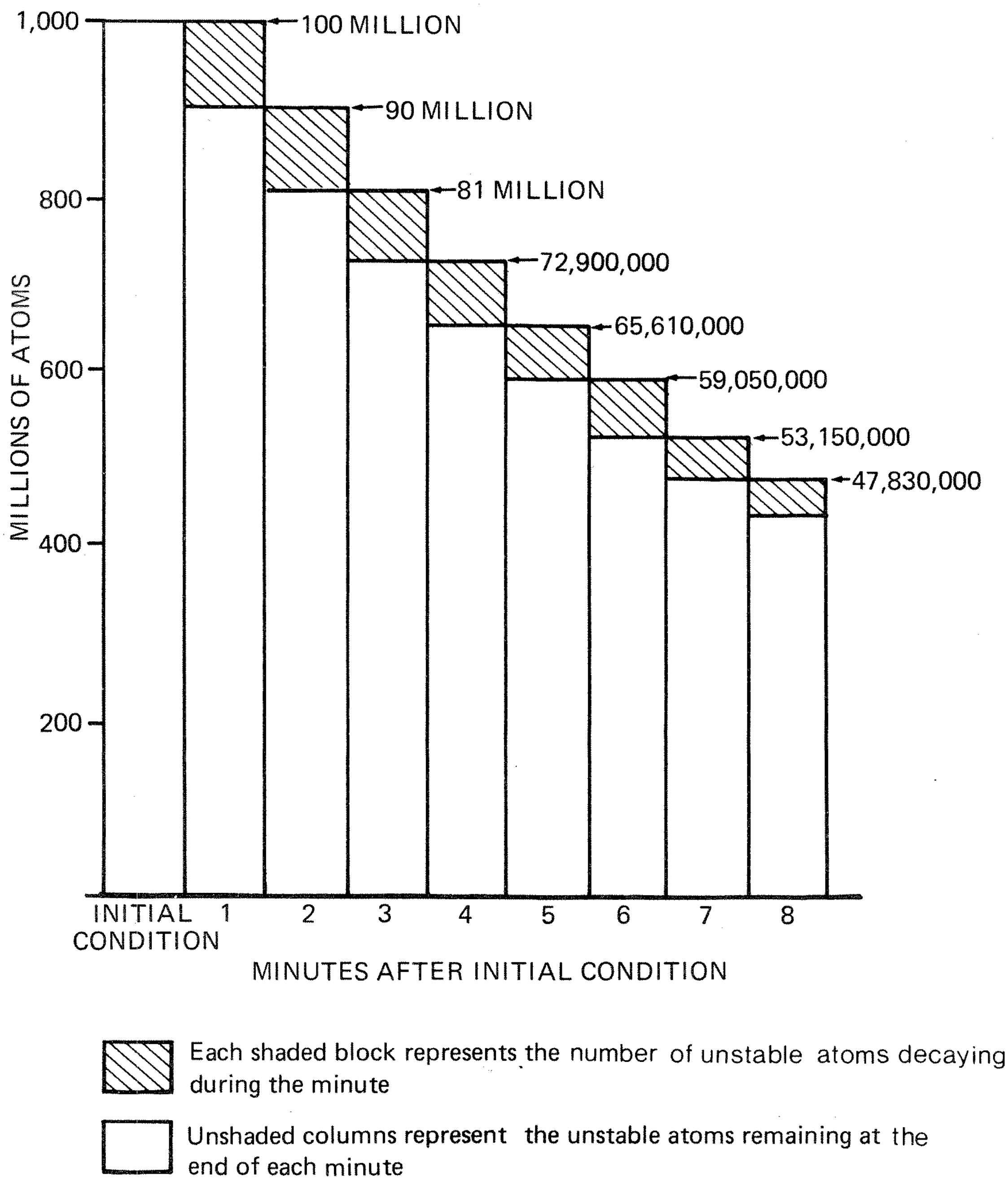
Atoms of the natural element, uranium, and an artificial element, plutonium, when penetrated by a neutron "projectile" will split in two, releasing energy. Each of the two pieces or "fission fragments" is like the nucleus of an atom of some element of medium weight--except for a surplus or deficit of neutrons. Because of this condition, such atoms are unstable, and sooner or later they adjust by emitting beta particles and gamma rays. After this adjustment, they have become atoms of another element which if still unstable undergo further adjustments until stability has been attained. It is this process of adjustment that is called "radioactivity" and the unstable atoms are called "radioactive."

Radioactive atoms have an interesting and important characteristic. The process of adjustment does not occur at a set time or in a set pattern. Rather, some atoms of a particular kind adjust quickly; others of the same kind take a long time. At any time, every atom of the group has the same chance of adjusting in the next instant, and this chance does not change as time goes on.

Think of a speck of an imaginary radioactive element consisting of a billion unstable atoms. In any given minute, every atom of this imaginary element has, let us say, a 10 percent chance of adjusting by giving off one beta particle and one gamma ray. Then, during the first minute, 100 million atoms would adjust (10 percent) giving off 100 million beta particles and 100 million gamma rays. There would be only 900 million unstable atoms left. In the second minute, 10 percent of these would adjust, emitting 90 million beta particles and an equal number of gamma rays. In the third minute, 10 percent of the remaining 810 million would adjust and so on. As time passed, there would be fewer and fewer unstable atoms remaining, and the number of beta particles or gamma rays emitted each minute would get smaller and smaller. This continuous decrease in the radiation emitted is called radioactive decay.

During the first 7 (more accurately 6.93) minutes, half the atoms of our imaginary element would have adjusted to become atoms of a stable element. The radiation being emitted per minute by the remaining half would be only half as much as in the beginning. In another 7 minutes, only one-quarter would be left and so on. We would say that this imaginary radioactive element has a "half-life" of 7 minutes.

HYPOTHETICAL RADIOACTIVE MATERIAL HAVING 10 PERCENT DECAY PER MINUTE



PANEL 3

DECAY OF THE FISSION-PRODUCT MIXTURE

Each of the 300 or so radioactive materials (fission products) created as the result of nuclear fission has its own characteristic half-life that defines its rate of decay. One fission product of special concern that will be discussed later, a particular form of radioactive iodine, has a half-life of about 8 days. Another that has received much publicity, one of the forms of strontium, has a half-life of about 28 years.

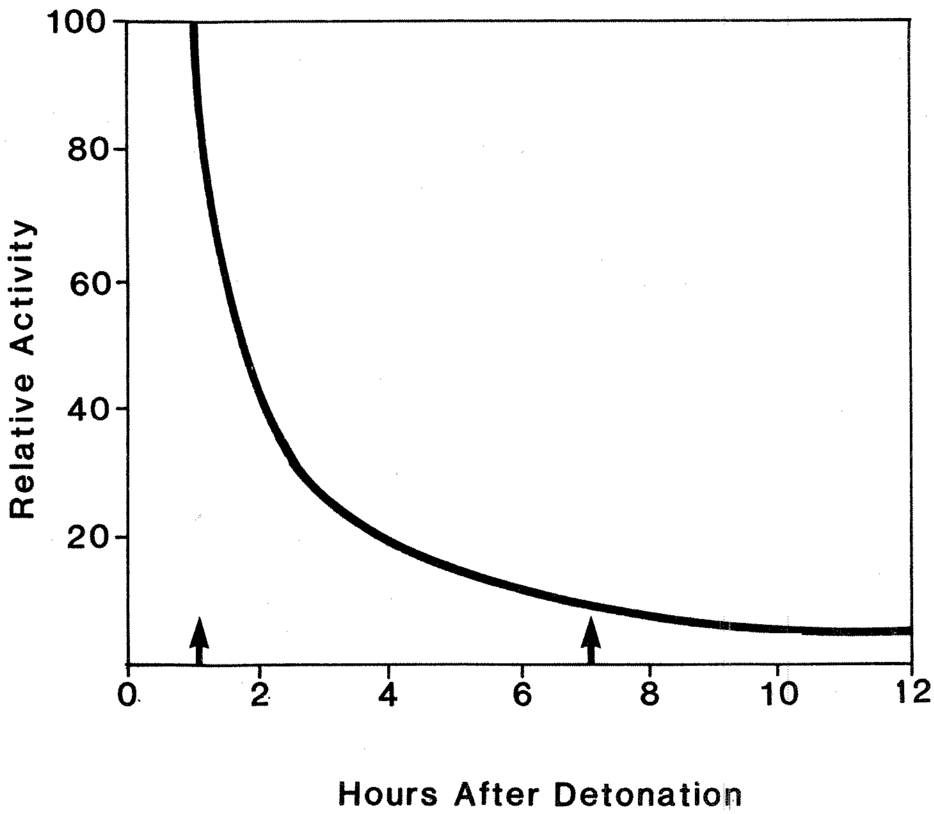
Naturally, at very early times after fission, those radioactive elements with very short half-lives contribute most of the radiation, and the decay of the fission-product mixture is very rapid. As these elements are depleted through the decay process, the longer-lived elements become more and more dominant. The overall decay of the mixture becomes slower and slower as time passes. A very rough rule of thumb for emergency planners is that the half-life of the fission-product mixture is about equal to the time interval after detonation at which the measurement was made. In other words, if a fallout radiation measurement is made at, say, 4 hours after detonation, the radiation intensity would be reduced by one-half about 4 hours later. Actually, fallout radiation decay is somewhat faster than this rule of thumb would suggest.

A more accurate estimator of radioactive decay of mixed fission products is the "7-10 Rule." This rule says that the radiation intensity is reduced tenfold for each sevenfold passage of time after detonation. For example, if a fallout radiation measurement is made at 4 hours after detonation, the intensity would be one-tenth as much at 28 hours after detonation. It would be one-hundredth of the original reading at 7 times 28 hours or a bit over 8 days after detonation. The 7-10 Rule gives reasonably good estimates up to about 6 months after attack. Subsequently, the dose rate decreases at a much more rapid rate than is predicted by this rule. The rule does not apply when the fallout results from more than one detonation at different times.

As we have seen in chapter 5, the fission-product radiation is a component of initial nuclear radiation (INR) during the first minute after fission. At 1 hour after fission, the radioactivity of the fission-product mixture is about 125 times less than it was at 1 minute. The illustration shows the rate of decay from 1 hour to 12 hours, using an arbitrary level of 100 at 1 hour. Note that the level is down to 10 at about 7 hours as the 7-10 rule would predict.

RATE OF DECAY OF FISSION PRODUCTS

AFTER A NUCLEAR DETONATION



PANEL 4

WHAT FALLOUT IS

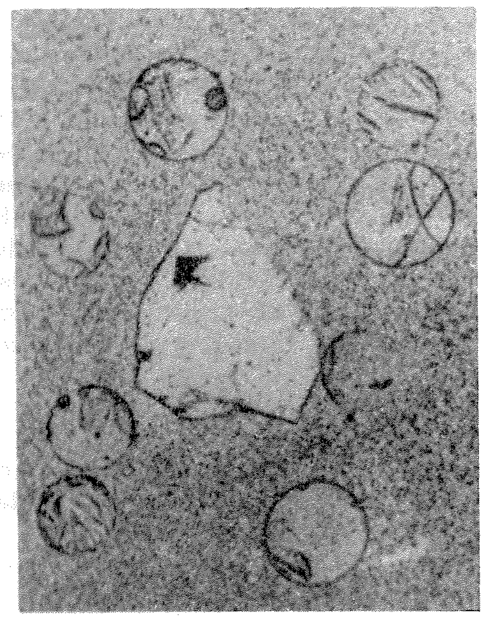
Each megaton of fission yield produces about 125 pounds of fission products. Thus, a 500 KT surface burst of 50 percent fission and 50 percent fusion would produce about 31 pounds of fission products. At 1 minute after fission, each ounce of these products is emitting gamma rays comparable to those from 15,000 tons of radium.

In addition, an explosion of any kind, occurring near the surface of the earth, causes material to be thrown up or drawn into the "chimney" of hot rising gases. A 500 KT surface burst carries aloft about 200,000 tons of soil and other surface materials in the stem and mushroom cloud of the detonation. Thus, the material that ultimately returns to earth as "fallout" from a ground surface burst is almost entirely soil. The radioactive residues incorporated in this soil are actually "trace elements" in a concentration of less than one-tenth part per million.

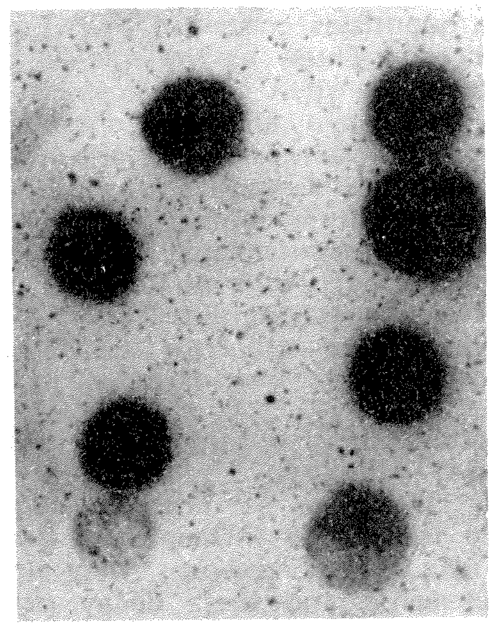
Soil drawn into the very hot fireball is vaporized. As the rising fireball cools, material entering later is only melted; and, as the fireball cools further and forms the mushroom cloud, some material reaching the cloud level is virtually unchanged. As the fireball cools below the boiling point of the vaporized soil material, it begins to condense into liquid droplets, which eventually solidify into glasslike particles.

These particles are tiny. The size of fallout particles is generally measured in microns, which is a length equal to one-millionth of a meter. To put these sizes in perspective, consider that 1000 microns--a millimeter--is about the thickness of a thin dime. A human hair 100 microns thick can be seen with the naked eye but a spherical particle of the same size is difficult to see without a microscope. Tobacco smoke consists of many very fine particles less than a micron in diameter. Fallout particles deposited in fallout areas defined by a dose rate exceeding 0.5 roentgens per hour generally range from about 50 microns to several millimeters in size.

The left-hand photograph shows a microscope picture of some fallout particles from a small-yield surface burst at the Nevada Test Site. The right-hand picture is a "radiograph" of the same particles showing the effect of radioactivity on a photographic film. These radioactive particles are a transparent green-yellow glass with the radioactivity distributed more or less uniformly throughout their volumes. Note that the large irregular particles in the left-hand picture, which does not show up in the right-hand picture, appears not to contain radioactivity.



PHOTOMICROGRAPH OF
THIN–SECTIONED PARTICLES
(greatly magnified)



RADIOGRAPH OF THE
SAME PARTICLES

Source: Reference 6

PANEL 5

WHY ALL FALLOUT IS NOT ALIKE

Let us pursue the matter of how fallout is formed a bit further. The formation of fallout is complicated because each of the many elements involved possesses characteristic properties that determine the temperatures at which it changes from a gas to a liquid and from a liquid to a solid. Those with low boiling points are termed "volatile," whereas those with very high boiling points are termed "refractory."

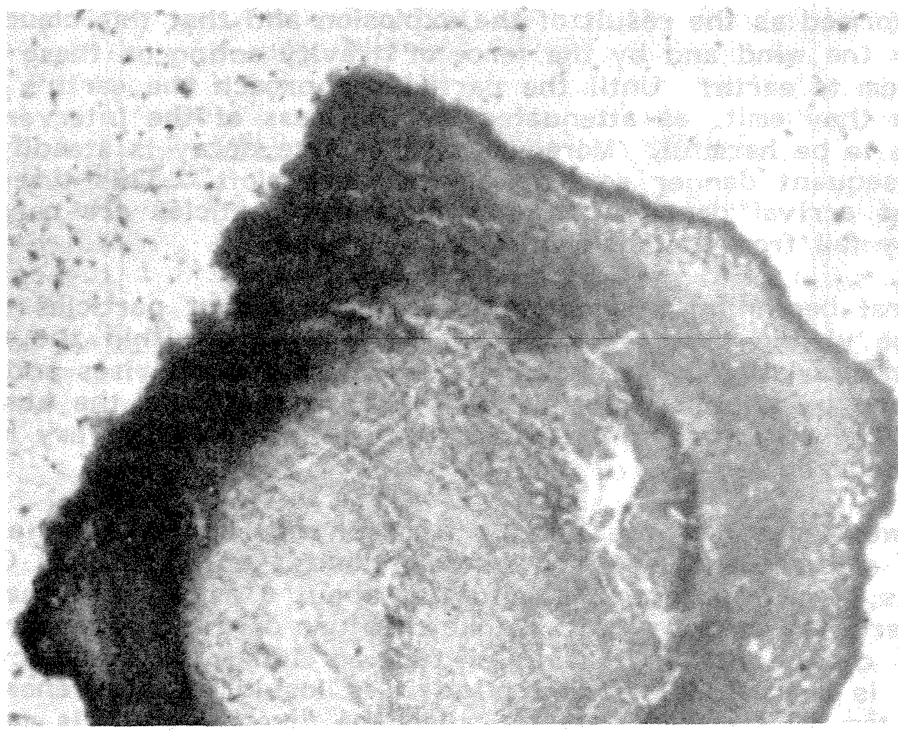
In general, entrapment of the radioactive materials, which are present in minute quantities compared to the soil, will occur only after condensation has occurred. Thus, as the fireball cools, the first major step in formation of fallout occurs when the vaporized soil condenses. Then those radioactive elements that have already condensed are readily incorporated into the liquid droplets, as we saw in the previous photograph. The more volatile elements are at this stage still gaseous and not available. Some elements do not interact significantly until the bulk material has solidified. Hence, these volatile elements tend to lodge on the surface of solid particles, as shown in this microscope photograph of a particle of fallout from a megaton-yield surface burst at Eniwetok. The small, black spheres (which are radioactive) shown adhering to the surface of a much larger coral sand grain were formed by vapor condensation.

Simultaneously, another important process is taking place. The particles formed range in size from a few microns up to several thousand microns. The larger particles fall away from the rising cloud at a relatively early time under the influence of gravity and the turbulent motion of the fireball. As a consequence, they are found to be deficient in the more volatile elements and their decay products, such as strontium, while the smaller particles that continue to rise with the nuclear cloud are enriched with the volatile species. Technically, this is known as "fractionation."

In simple terms, it means that all fallout is not alike. The heavier particles that fall to the ground in a matter of hours contain most of the radioactivity produced by the explosion, but they are deficient in the more volatile radioactive elements. Furthermore, most of the radioactive atoms are locked within the glassy particles. The smaller particles, on the other hand, which are enriched in the volatile species, fall to earth very slowly over a period of weeks, months, and even years.

A change in the fission-product mixture with particle size (and, hence, distance from the detonation) does occur. However, it is not so great as to invalidate the radiation decay rates we have already discussed and is of great importance to the questions of whether contaminated water can be drunk or whether food can be grown in fallout areas. Many myths have been born from observations made on "worldwide" fallout or at great distances from test explosions without recognition that "all fallout is not alike."

PANEL 6



PHOTOMICROGRAPH OF SECTION OF PART OF A CORAL SAND GRAIN
SHOWING ADHERING SMALL SPHERES
(Greatly magnified)

Source: Reference 6

PANEL 6

THE MUSHROOM CLOUD

A simple description of the fallout process might be that a cloud of particles is formed as the result of the explosion and that this cloud is then dispersed by the wind and by the force of gravity acting on these particles to return them to earth. Until the particles approach the earth's surface, the radiation they emit, as attenuated by the mass of the intervening air, is too remote to be harmful. Moreover, radioactive decay is steadily reducing the subsequent danger so long as they are aloft. This time interval before fallout arrival depends on how high the particles are carried and how fast they fall from that height.

A natural beginning assumption is that the fallout particles are contained in the visible cloud formed over ground zero within the first few minutes after detonation. The height to which this cloud rises and its size are determined by the heat energy of the detonation and the atmospheric conditions. The structure of the earth's atmosphere plays a very important role in this regard.

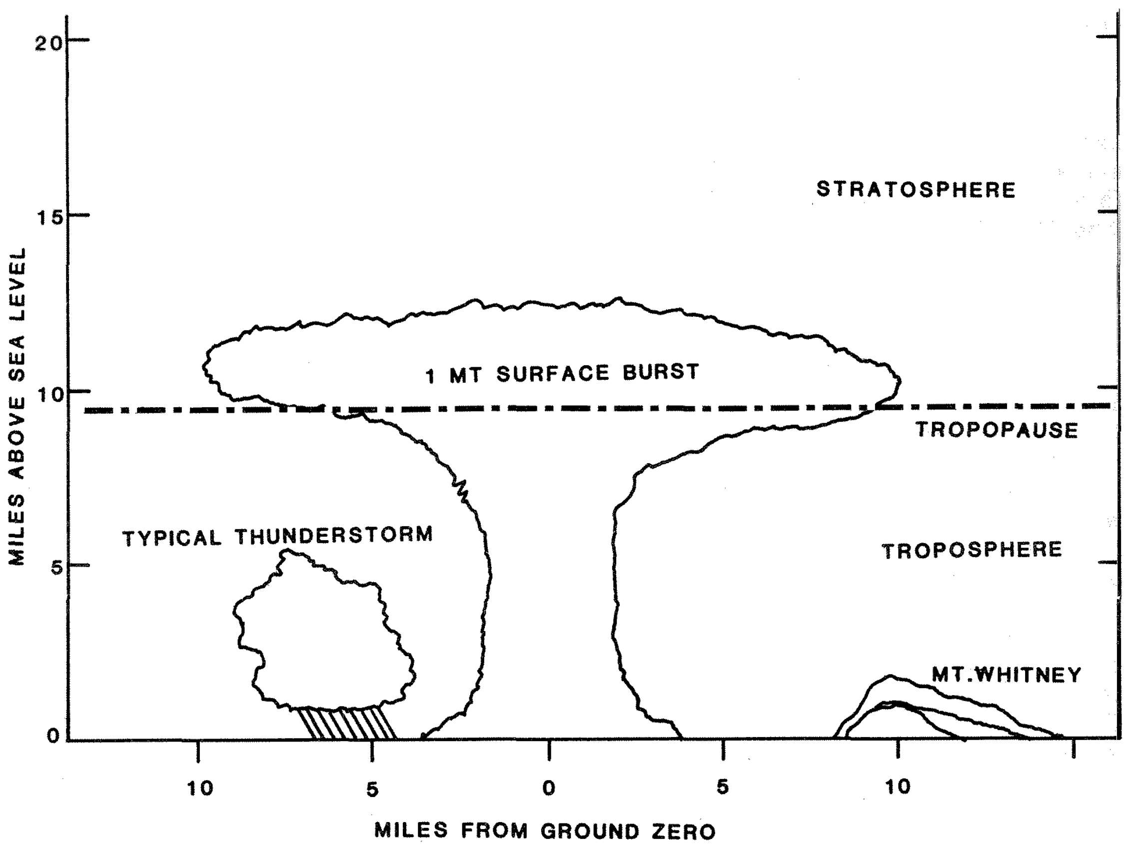
The lowest layer of the earth's atmosphere, known as the "troposphere," is a turbulent layer of winds, clouds, and storms. Over the United States, the troposphere extends up about 8 miles, somewhat higher in the summer than in the winter. A key feature of the troposphere is that the air gets colder with increasing altitude. Thus, the buoyancy of the rising cloud is maintained, even though it is losing its heat energy as it rises. The top of the troposphere, called the "tropopause," is marked by an air temperature minimum, above which temperatures increase in the stratosphere and mesosphere up to an altitude of 30 miles. As the rising cloud penetrates the stratosphere, it rapidly loses buoyancy and spreads laterally to a more-or-less stable size within 5 to 10 minutes after detonation.

Early attempts to explain the subsequent fallout on the ground by assuming that the radioactive particles fell from the visible cloud proved that the fallout near and around the detonation must have come from the region of the stem below the visible cloud. So both mushroom cap and its stem had to be taken into account. This illustration shows the average dimensions of the visible clouds from explosions up to one megaton yield. The diameter of the mushroom stem is about one-fifth that of the mushroom cloud.

THE VISIBLE CLOUD

NUCLEAR CLOUDS

YIELD	DIAMETER	HEIGHT
0.2 MT	8 miles	10 miles
0.5 MT	14 miles	12 miles
1.0 MT	20 miles	13 miles



PANEL 7

FALLOUT PREDICTION MODELS

Measurements of the fallout resulting from nuclear detonations have been done for a relatively few surface detonations during weapons tests in Nevada and in the Pacific. All of the megaton-yield tests were done at Eniwetok and Bikini Atolls where most of the fallout area was open ocean. Fallout researchers have tried to fit various models to these limited data in order to predict what the fallout situation would be for other weapon yields, burst conditions, and wind conditions. One of the key problems has been to assess the size and location of the radioactive cloud from which the fallout particles originate in their fall to earth.

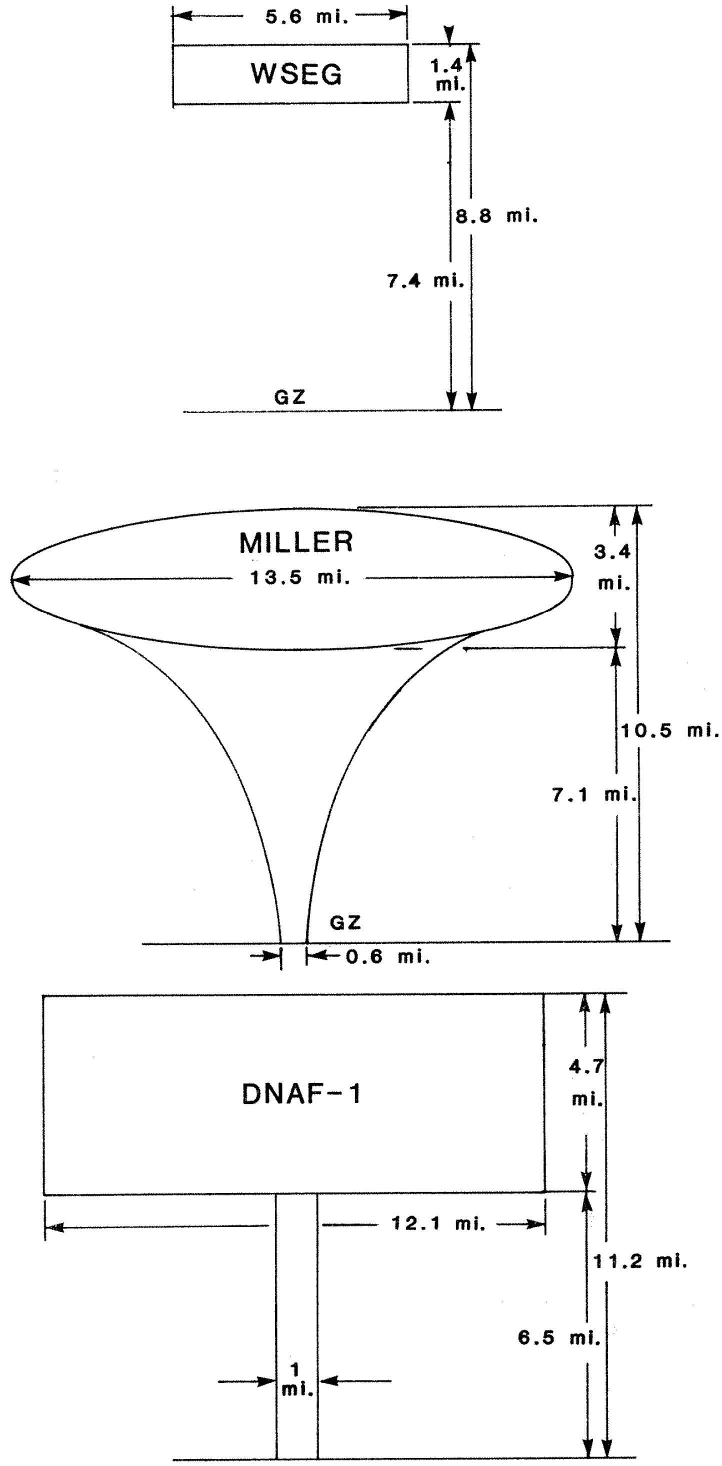
Shown here are the fallout clouds assumed in three fallout prediction models. The WSEG model, developed for the Weapons System Evaluation Group, has been perhaps the most widely used fallout predictions system. It forms the basis for the fallout models used by both the Federal Emergency Management Agency (FEMA) and the Department of Defense (DOD). The Miller model was developed for a predecessor agency of FEMA. It is able to match many important characteristics of fallout and has been used in research studies and civil defense exercises. (The fallout information in this chapter is based on the Miller model.) The DNAF-1 model was developed for the Defense Nuclear Agency in the early 1980's as a model that runs rapidly on computers. It uses analytical equations, does not require extensive computer memory, and updates certain of the features of the earlier models such as WSEG. It uses an approach which accounts for fallout from the stem, a feature lacking in WSEG but contained in Miller. The DNAF-1 is beginning to replace the WSEG model in large scale damage assessment studies.

The WSEG cloud is represented as a cloud disc without a stem. The WSEG cloud has a much smaller diameter than the Miller model, the cloud is thinner, and the cloud rises to a slightly greater height. In all three models the bottom of the stabilized cloud is about 6 1/2 to 7 1/2 miles above the ground for a 500 KT burst.

The cloud of the Miller model is in the shape of an oblate spheroid with dimensions approximating those of the visible cloud. Additionally, there is a horn-shaped "stem," which actually represents the volume swept out by the expanding fireball and cloud as it rises.

The DNAF-1 model retains the feature of the stem but uses a cylindrical cloud as in the WSEG model--but significantly larger. The height of the top of the DNAF-1 cloud approximates that of the Miller model cloud. Comparisons of the outputs of the DNAF-1 model with available fallout measurements from weapon tests are very good.

SEVERAL FALLOUT CLOUD MODELS FOR A 500 KT SURFACE BURST



Adapted from References 12, 19, 22

PANEL 8

AN EXAMPLE FALLOUT SITUATION

The Miller fallout model was first published as an internal Office of Civil Defense (OCD) research report in June 1962 by Dr. Carl Miller, head of the OCD Postattack Research Division. The model grew out of analysis of a great deal of data on the amounts, particle sizes, and chemical and radiological characteristics of fallout collected at nuclear weapons tests.

This illustration shows the cloud part of the model for a 500 KT surface detonation. The radioactive cloud is about four times wider than it is thick. The center of the cloud is about 8.8 miles above the ground, with the bottom 7.1 miles high and the top 10.5 miles high. Fallout particles and radioactivity are assumed to be mixed uniformly throughout the cloud volume and the fallout particles are assumed to begin to fall at detonation time. This is a simplified version of a much more complicated actual situation, but it fits the experimental results quite well.

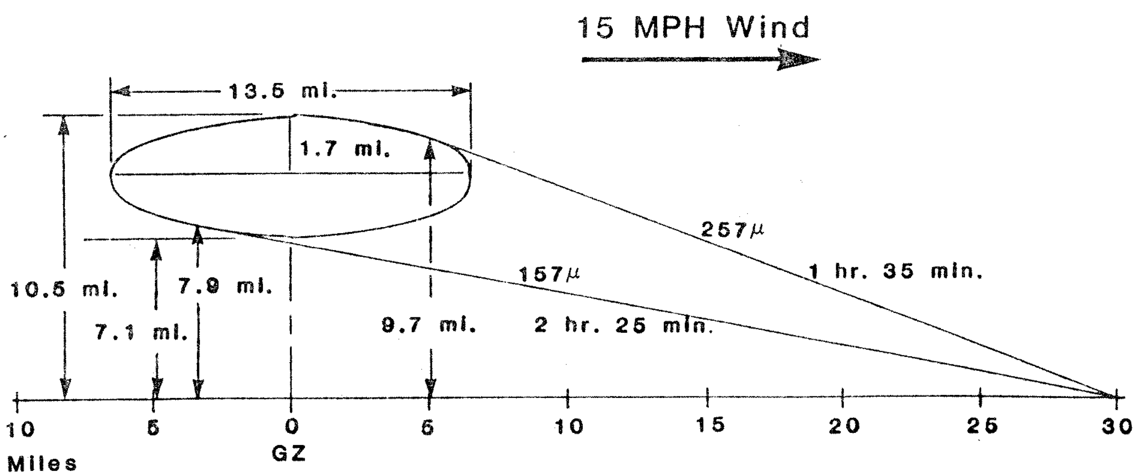
Consider a point on the ground 30 miles directly downwind from the detonation, assuming that a 15 mile per hour wind is blowing in the same direction at all altitudes. The model predicts that the first fallout particle to arrive will be the largest particle, 257 microns, deposited at this location. It will have come from the high forward edge of the cloud, about 9.7 miles up, and will arrive about 1 hour and 35 minutes after the detonation, as shown in the illustration. Larger particles will have fallen more rapidly and will have been deposited closer in. Particles of the same size elsewhere in the cloud will have followed parallel paths to closer in locations.

The last particle will arrive at the chosen point about 2 hours and 25 minutes after detonation. It will be the smallest particle, 157 microns, to arrive and will have come from the low rear edge of the cloud, about 7.9 miles altitude, as shown. Smaller particles and particles the same size elsewhere in the cloud will be deposited further downwind. All particles deposited during the 50 minutes between fallout arrival and cessation will be between these two sizes, with the midrange size about 207 microns, about half the size of the period at the end of this sentence.

At 30 miles, there will be about 1/3 of an ounce* of fallout particles deposited on each square foot of horizontal surface. If a 40-pound bag of fertilizer intended to cover 5,000 square feet were to be spread according to directions, the weight of fertilizer particles per square foot of lawn would be only about 1/8th of an ounce. Of course, fertilizer particles are rather large (about 1,000 microns, perhaps) but the more numerous fallout particles would be as readily visible.

*Since 1 ounce = 28.35 grams, this deposition is about 9.5 grams.

CLOUD FALLOUT
(500 KT Surface Detonation)



Adapted from Reference 8

THE FALLOUT PATTERN

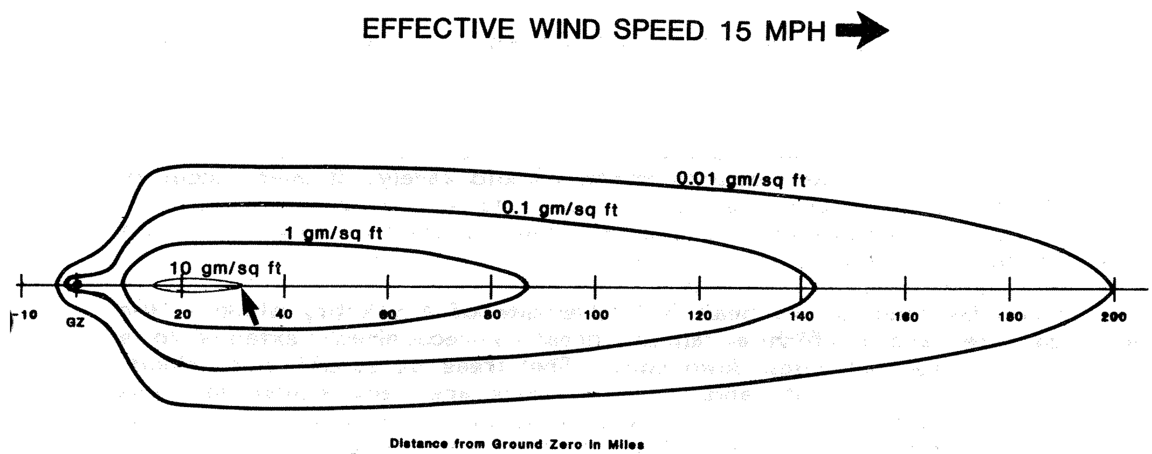
Fallout deposition from a 500 KT surface burst is shown here in the form of contours of equal weight of fallout. The unit of measurement is grams of fallout material per square foot of horizontal surface, which is the usual way fallout deposition is expressed. The effective wind speed is a uniform 15 miles per hour. The location 30 miles directly downwind, used in the previous example, is marked by an arrow. A set of contours of equal value, such as shown here, is commonly called a fallout "pattern."

The pattern of the weight of fallout deposited per unit area of ground will be new to most readers, even those who have had radiological training, because most fallout patterns used in training and exercises show the intensity of the radiation that might be observed as the result of fallout deposition. We chose to show the contours of mass deposition first in order to emphasize that fallout consists mainly of siliceous particles of sensible size. It is these particles that fall through the air and are blown by the wind. They would have fallen and been blown downwind according to their physical nature whether or not they were radioactive. The amount of material deposited is quite substantial and is readily seen with the naked eye. Like desert sand, it can drift into gutters and sift into cracks under the action of wind and rain. It can be vacuumed, brushed off, flushed away, and filtered out just as any particles of the same size range.

This idealized pattern can be thought of as an elongated "shadow" of the mushroom cloud and stem. The relatively small knob around ground zero represents the stem, and the much larger "cigar" shapes represent the cloud. The stem fallout pattern is nearly the same width as the visible stem but the cloud fallout pattern is very much wider than the 6 to 15 mile clouds described in panels 7 and 8. The reason is that atmospheric winds never blow uniformly even though the effective wind is in a single direction. Fallout particles follow a more circuitous route in falling to the ground and, hence, are spread more widely. The outermost contour shown here is almost 50 miles across at its widest point.

It should be emphasized that the fallout patterns shown in this manual, with the exception of that of panel 23 in this chapter, are idealized patterns produced by fallout models and use constant winds. The reader is cautioned that fallout patterns from real bursts may, and probably would, differ in many respects from these idealized pictorizations.

MASS DEPOSITION PATTERN
(500 KT Surface Burst)



Source: Reference 12

MAXIMUM EXPOSURE RATES

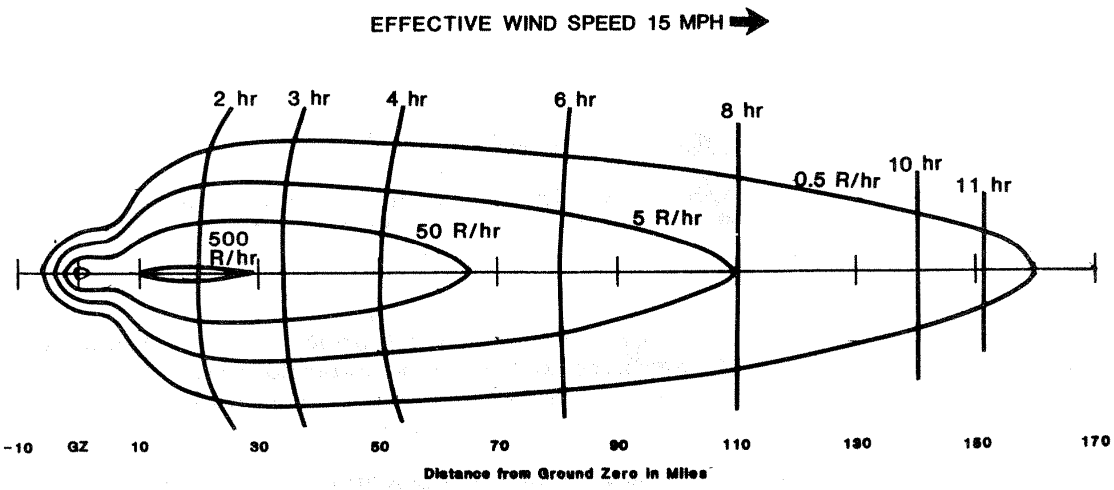
When fallout particles first arrive at a point on the ground and begin to accumulate, the radiation from these particles also increases. Radioactive decay is reducing the rate of exposure from those particles that have fallen, but additional fallout generally arrives so rapidly that the total intensity continues to increase. Shortly before the time of fallout cessation, a maximum or "peak" exposure rate occurs, after which the intensity of radiation begins to decrease through radioactive decay.

If the fallout were deposited rather uniformly on a glassy-smooth surface of very large extent, the maximum or peak exposure rate 3 feet above the smooth surface following the 500 KT surface detonation would be as shown by these idealized contours. The more-or-less vertical lines across the pattern give the time after detonation at which the peak occurs. This deposition on a glassy-smooth surface would rarely, if ever, occur in reality; but, as subsequent panels will show, actual conditions are so variable that the "smooth, infinite plane" situation is used as a base case for fallout models and calculations.

It can be seen that a peak exposure rate of 0.5 R/hr, which is the accepted level above which a fallout threat is recognized, extends to a distance of about 160 miles downwind. The areas of "stem" and "cloud" fallout are clearly evident, and these contours are very similar to those shown in panel 10.

There are two contours enclosing areas where the peak exposure rate will exceed 500 R/hr, one in the stem region and one in the cloud region. Our example location 30 miles downwind is almost in the downwind peak area. Here, the "true" exposure rate 3 feet above a smooth, infinite plane would reach a maximum of about 470 R/hr at fallout cessation, about 2 hours and 25 minutes after the detonation. This exposure rate is very nearly the highest rate that would occur.

PEAK EXPOSURE RATE PATTERN
(500 KT Surface Burst)



- Contours in roentgens per hour (true ionization rate at three feet above a smooth infinite plane)
- Vertical curves show peaking times in hours after detonation
- Fission yield 50%

Source: Reference 12

VISIBLE ASPECTS OF FALLOUT

Upon reentry following weapons tests, the fallout areas were usually noted as being distinguished by a coloration of ground and foliage. Observations of the fallout event itself was often marked by visible fallout and "lowering of the sky" similar to that observed in rain showers.

In 1964, the eruption of the volcano Irazu in Costa Rica provided an opportunity to observe fallout that was remarkably similar to fallout from nuclear weapons except that it was not radioactive.* This permitted immediate on-site observations not possible in nuclear tests. It was found that deposits of fallout were easily visible when they amounted to 1 to 3 grams per square foot of surface. This level corresponds roughly to the severe fallout area where exposure rates may exceed 50 R/hr.

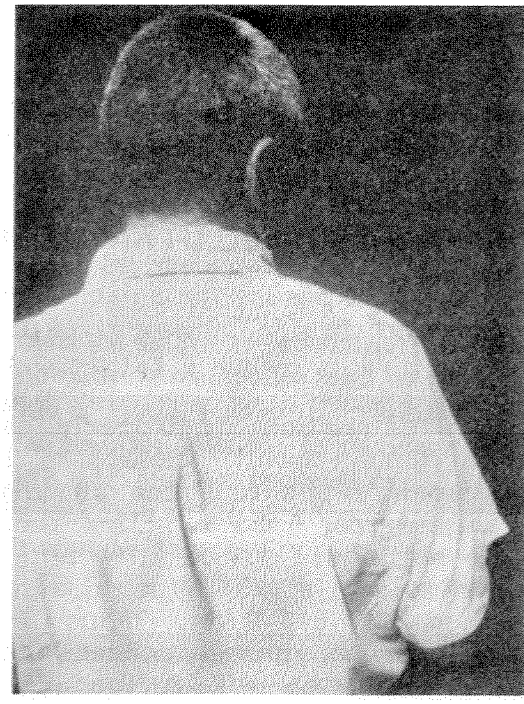
The upper photograph shows the back of an individual exposed in such a situation. The first sensation when fallout begins arriving is the impact of particles on the nose and forehead. After a few minutes, the second sensation is a gritty feeling on the lips and teeth. (These fallout particles are too large to enter the nose by normal breathing.) On clothes, the particles collect in the folds, in cuffs, and under belts. People with open-necked shirts feel the particles sifting into underclothing. So long as clothes are dry, the particles are readily removed by shaking. They are not so readily removed from damp cloth.

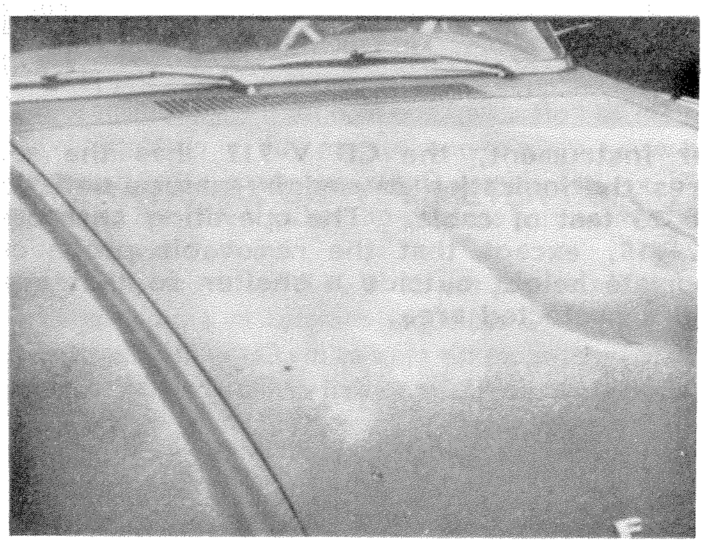
The lower photograph shows a fallout deposit on an automobile. Dry particles are, to a large extent, cleaned by the winds but washing is required to remove all particles from the surfaces.

It may be too strong a statement to say that under all conditions fallout will be readily visible whenever a significant radiation hazard exists. Proper use of radiation instruments will remain the basic tool for control of radiation exposure. But it can be said that, whenever fallout is evident as described here, a significant radiation exposure is in prospect.

*The ash deposited after the Mt. St. Helens eruption in 1980 was less like fallout being more talc-like than that at Irazu. However, it was also deposited by the wind patterns much as was that from Irazu and that from a nuclear ground burst detonation. Such a nuclear detonation would produce far less material than from either of these volcanic eruptions.

WHAT FALLOUT LOOKS LIKE





Source: Reference 17

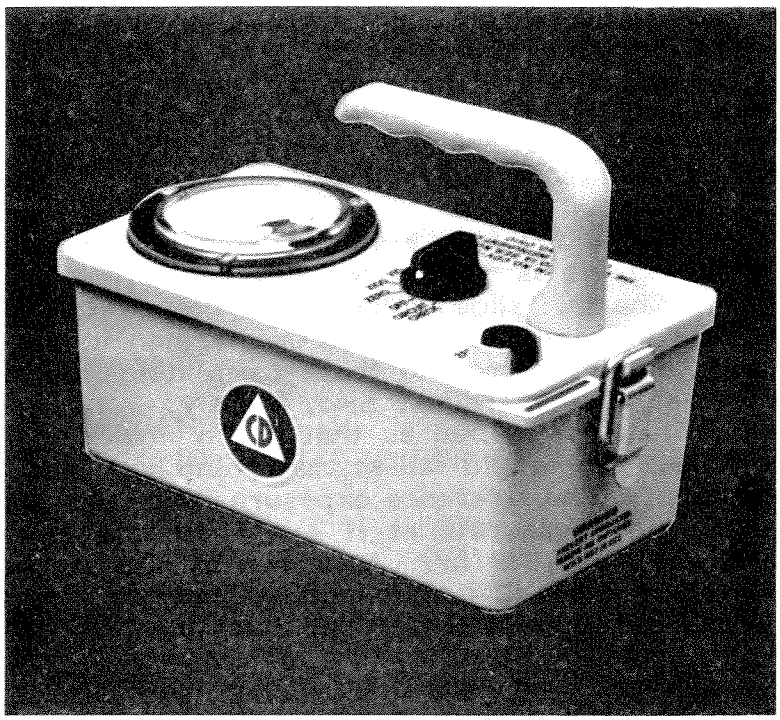
PANEL 12

MEASURING FALLOUT RADIATION

Although the fallout particles themselves will be apparent to the alert observer under most circumstances, the preferred basis for control of radiation exposure is measurement of the radiation itself. Gamma radiation is the chief threat, as outlined in chapter 5. The dosimeter, used to measure the cumulative amount of gamma radiation received, was described in that chapter. Shown here is the CD V-715, which measures the gamma radiation exposure rate. This is the "workhorse" instrument for exposure control, since knowledge of the exposure rate and the radioactive decay permits estimates of current and future radiation exposure; whereas, the dosimeter simply records the exposure already received.

For the 500 KT surface detonation, a properly calibrated CD V-715, held at waist height over a glassy-smooth surface of large extent, would measure approximately the peak exposure rates shown in panel 11. The scale on the instrument ranges from 0 to 5. The knob under the handle can be rotated to four scale settings: 0.1, 1, 10, and 100. The full-scale reading when the knob is set to 0.1 is 0.5 R/hr; at a setting of 1, 5 R/hr; at a setting of 10, 50 R/hr; at 100, 500 R/hr. Thus, the contours in panel 11 are the full-scale readings for the four scale settings on the CD V-715. This means that throughout the area within the 500 R/hr contour, the exposure rate would be "off scale"--too high for the instrument to read. This would be true if the real world were a glassy-smooth surface with no obstructions. As will be seen in panel 16, the real world is quite different. One consequence is that the situations in which the exposure rate will exceed the measuring capacity of the CD V-715 would be rare and momentary.

A very similar instrument, the CD V-717, has the sensitive element (that which measures the ionization caused by gamma radiation) enclosed in a probe attached to 25 feet of cable. The operating characteristics are the same as the CD V-715, except that the removable probe can be prepositioned at an appropriate height outside a shelter so that measurements can be made from within a protected area.



THE OPERATIONAL SURVEY METER CD V-715

EXPOSURE-RATE MEASUREMENT AND PREDICTION

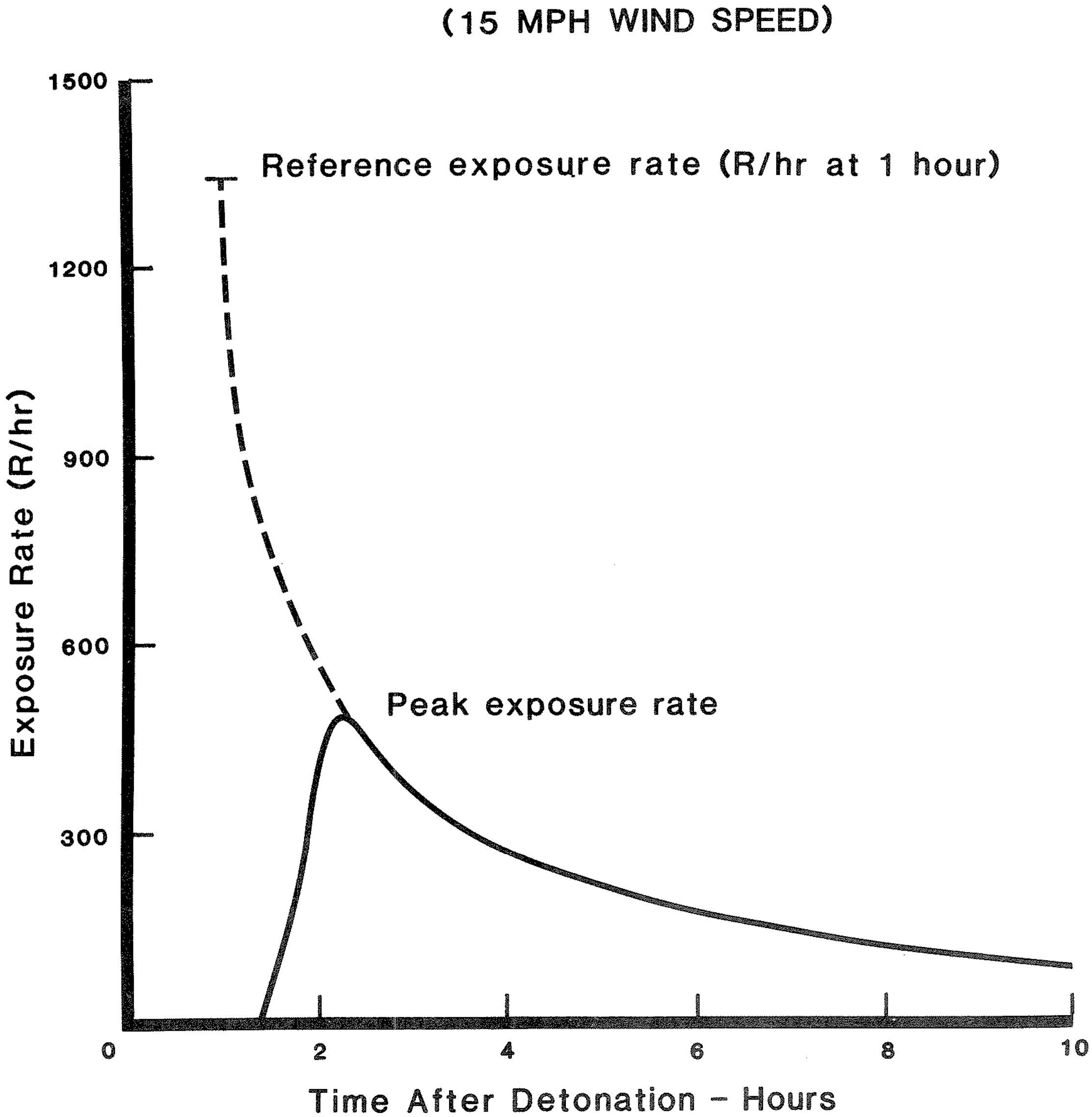
We saw in panel 11 that the location 30 miles directly downwind from the 500 KT surface detonation was just outside the "hottest" part of the fallout pattern, and, in panel 9, that fallout would begin to arrive about 1 hour and 35 minutes after detonation. As shown on this graph, the exposure rate would rise rapidly, exceeding 50 R/hr within 10 minutes. The rate would peak at about 470 R/hr some 2 hours and 25 minutes after detonation and then decrease, quite rapidly at first and more slowly later on. Six and one-half hours after peak (nearly 9 hours after detonation), the rate would drop below 100 R/hr.

Once the fallout deposition from a single detonation is complete and the exposure rate is falling, it is generally possible to estimate the future radiation situation. Charts, slide rules, and nomograms exist for this purpose. Radiological officers and monitors are trained in the use of these tools. One concept that is common to these calculating devices is the use of a reference rate at a standardized time; namely, 1 hour after detonation. This exposure rate is defined as that which would be observed at a location if all the fallout that would fall at that point had been deposited by 1 hour after detonation. The reference exposure rate (also variously called "standard intensity" and "dose rate at H + 1") for the location we have been considering is about 1,375 R/hr. As shown by the dashed curve, this is a fictitious rate since deposition of fallout has not yet begun at 1 hour. This is generally true throughout the fallout area for weapons in this yield range.

By the use of the reference exposure rate and the appropriate calculating rules, it can be determined that the rate at 30 miles directly downwind at the end of the first day would be about 30 R/hr; at 1 week, about 3 R/hr; at 1 month, about 0.5 R/hr; and at 4 months after attack, about 1/10 R/hr (or 100 mR/hr, an mR or milliroentgen being one one-thousandth of a roentgen).

As we saw in chapter 5, it is the radiation exposure that injures people; and since the exposure rate is constantly changing in a fallout situation, special calculations must be made to predict future exposures. To get a general idea of how this is done, the emergency planner might read the Fundamentals Course for Radiological Monitors (SM-81) or, better still, enroll in the self-directed study courses, available through FEMA. The methods taught would tell us that the potential unprotected exposure at 30 miles downwind would be about 200 R at time of peak exposure rate, 2,300 R at the end of 1 day, 3,500 R at 1 week, 4,100 R at 1 month, and about 4,500 R at 4 months.

FALLOUT SITUATION AT 30 MILES DIRECTLY
DOWNWINDFROM A 500 KT SURFACE BURST



PROTRACTED EXPOSURE AND BIOLOGICAL RECOVERY

In panel 12 of chapter 1, we exhibited the radiation penalty table shown opposite. In chapter 5, we described what is known about the biological consequences of "brief" exposures of gamma radiation. The exposures shown in the "1 week" column are consistent with those given in chapter 5 for the same medical consequences. Therefore, a 1 week exposure may be considered "brief," especially as the exposure estimates of the previous panel indicate that two-thirds of the 1 week exposure is received in the first day. The reason why the exposures shown in the "1 Month" and "4 Months" columns are larger is because the human body has some capacity to repair the damage caused by ionizing radiation.

In panel 3 of chapter 5, it was noted that large single exposures can cause acute sickness or death, whereas small daily exposure may be tolerated without causing radiation sickness. An exposure of 600 R will be lethal when received as a brief exposure. The same exposure accumulated over a period of 20 years, if delivered in equal daily amounts (less than 0.1 R/day), probably will not cause any recognizable effect. The radiation penalty table recognizes this recovery principle by "allowing" greater exposures, if spread over a period of many weeks or months. It is believed, also, that most of the later signs of radiation injury (panel 6 of chapter 5) are also less likely if exposure is protracted.

The lower table shows a possible situation at 30 miles directly downwind. The exposures in the open are those noted in the previous panel. Now imagine a shelter at this location that has the capability of reducing the unprotected fallout exposure by a factor of exactly 15. (The characteristics of real shelters are described in panels 18 to 22.) The column labeled "In Shelter 15" shows the 1 week calculated exposure to be 230 R, just short of the 250 R shown in the radiation penalty table. Few, if any, deaths would be expected. If one were to remain in "Shelter 15" for a month, the exposure would be 273 R and one would have 77 R "to spare," according to the second row in the table. However, since the exposure rate over the smooth infinite plane would be nearly 0.5 R/hr at 1 month, not much time could have been spent outside in the interim without exceeding the body's repair capability. It might have been wiser, in this circumstance, to have used the "spare" exposure during the second week to move out of the heavy fallout area.

It can also be seen that staying in Shelter 15 for 4 months would have left 200 R to spare (500 R - 300 R). This would appear to be a good deal but would allow only a couple of hours a day outside the shelter, on the average.

The final column represents a nearby shelter having the capability of reducing the unprotected fallout exposure by a factor of 40. Being in Shelter 40 is better than being in Shelter 15, but , in either case, the table indicates that biological recovery is insufficient to allow much time outside the shelter.

RADIATION PENALTY TABLE

Acute Effects \ Accumulated Exposure (R) In any	1 Week	1 Month	4 Months
Medical Care Not Needed	150	200	300
Some Need Medical Care Few if Any Deaths	250	350	500
Most Need Medical Care 50% + Deaths	450	600	*

* Little or no practical consideration
Source: Adapted from Reference 3

EXPOSURES AT 30 MILES DOWNWIND
(500 KT surface burst, 15 mph wind)
(Roentgens)

Time	In Open	In Shelter 15	In Shelter 40
1 Week	3450	230	86
1 Month	4100	273	103
4 Months	4500	300	113

ACTUAL EXPOSURE RATES

Under actual operating conditions, measured exposure rates and consequent exposure of people will be generally lower than those implied in previous panels for two main reasons: (1) most real surfaces are not smooth, and (2) many contaminated areas (roofs, streets, and the like) are of limited extent. Typical reductions to be expected are shown in these sketches.

Smooth paved areas, unbroken by curbs, gutters, and the like offer little reduction due to surface roughness. This is also true of packed snow or ice. Macadam and rough pavement will result in a "reduction factor" of about 0.8. Sand, bare soil, and grassy areas offer a reduction factor of about 0.7. Gravelled roads and roofs will reduce the exposure rate about one-half, a reduction factor of 0.5. Fallout on very rough or plowed ground will produce an exposure rate only about 0.4 of that on a smooth, infinite plane.

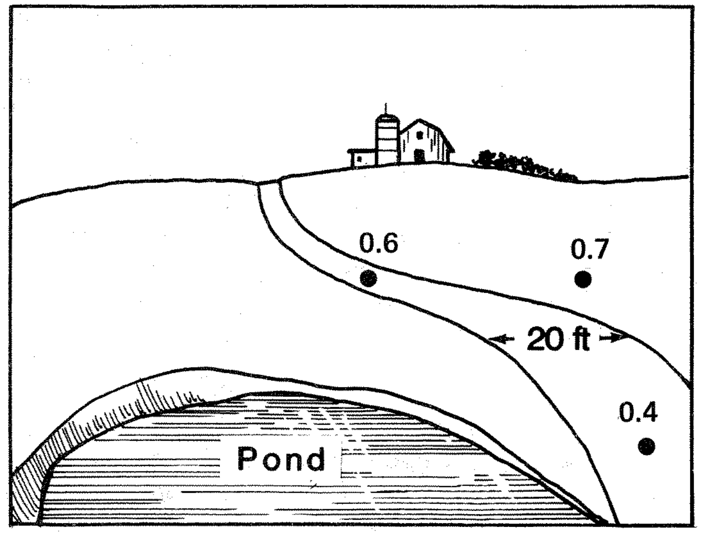
In the sketch of "Rural America," at the top of the opposite panel, most of the reduction is due to the roughness of grassy fields and macadam or gravel roads. An exception is the value of 0.4 on the road next to the pond where the fallout material has sunk to the bottom of the pond, thereby limiting the extent of the contaminated area affecting that point.

In "Main Street USA," bottom sketch, the buildings restrict the extent of the area contributing to the exposure rate. Here we have assumed that the street is smooth pavement without curbs. The reductions shown in the street are due to the presence of the buildings, being greater near the buildings than in the center of the street. The reduction factors on the roofs are due to both the rough gravel surface and the fact that the height of the buildings reduces the contribution from the surrounding ground.

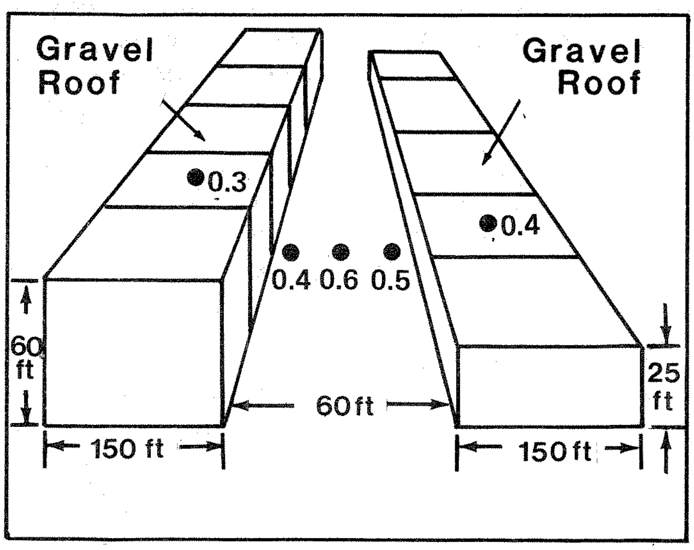
An operational implication is that radiation levels measurements reported by radiation monitors are very unlikely to allow the drawing of smooth contours, such as those shown in panel 11, since the measurements will vary considerably depending on the environment in which the measurements are made.

In summary, measured exposure rates would vary according to the roughness of the surfaces upon which fallout material has deposited, as well as the unbroken extent of these surfaces. The net result would be measured exposure rates generally ranging from 40 to 70 percent of what would have been measured if the same amount of fallout material had been deposited uniformly on the "standard" (and imaginary) smooth, infinite plane surface.

REAL WORLD EXPOSURE RATES
(for 1 R/hr on a smooth infinite plane)



RURAL AMERICA



MAIN STREET USA

Source: Reference 14

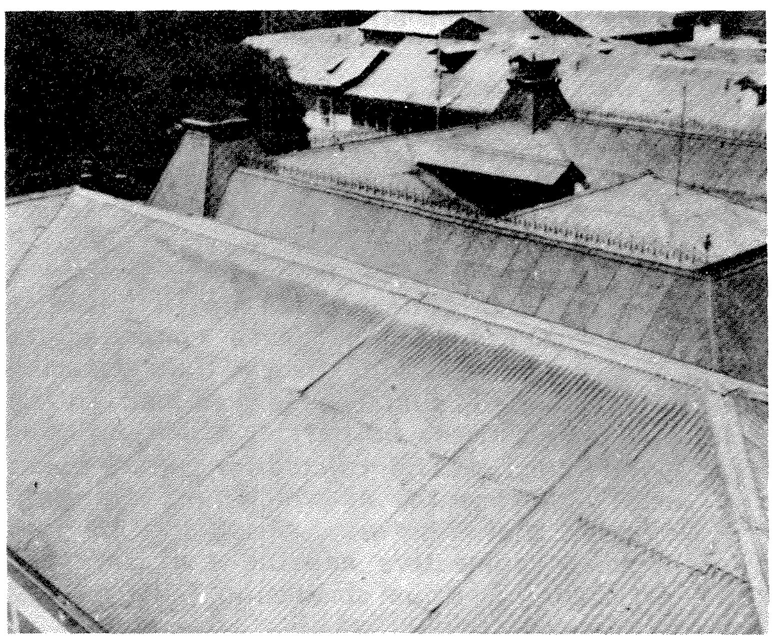
ANOTHER VARIABILITY--WEATHERING

Another variability that will occur in practice results from the movement of fallout particles by the action of wind and rain, generally called "weathering." This effect can be quite marked on smooth surfaces. The upper photograph shows a view of street and sidewalk contamination on San Jose, Costa Rica, after the volcanic fallout particles had been redistributed by wind and passing vehicles. The particles have accumulated near the curb and in cracks and small depressions in the concrete pavement. Often, a triangular-shaped concentration of fallout particles will occur at a wind-protected corner, as shown here. If this fallout had been radioactively contaminated, this pedestrian would have been approaching a "hot spot," a limited area of concentrated fallout in which the exposure rate would have been much higher than average--much higher than that over a uniformly-contaminated, smooth infinite plane.

The lower photograph shows the distribution of fallout-like particles on roofs. Particles tended to be scoured off the windward sections and to accumulate on the lee side of the roof just below the ridge, as shown. The particles drifted into roof gutters and other wind-protected places. Rain would wash particles toward the drains and ultimately into the storm sewers where they would become shielded from the surface above. Thus, in the long run, weathering acts to further reduce the hazard to people. But, in the process, hot spots are created causing irregularities in the local radiation pattern.

Wind and rain do not tend to move fallout particles from natural soil or grassy areas. Consequently, radiation level measurements in Rural America will be much less variable than those in urban areas.

WEATHERING EFFECTS



Source: Reference 17

PANEL 17

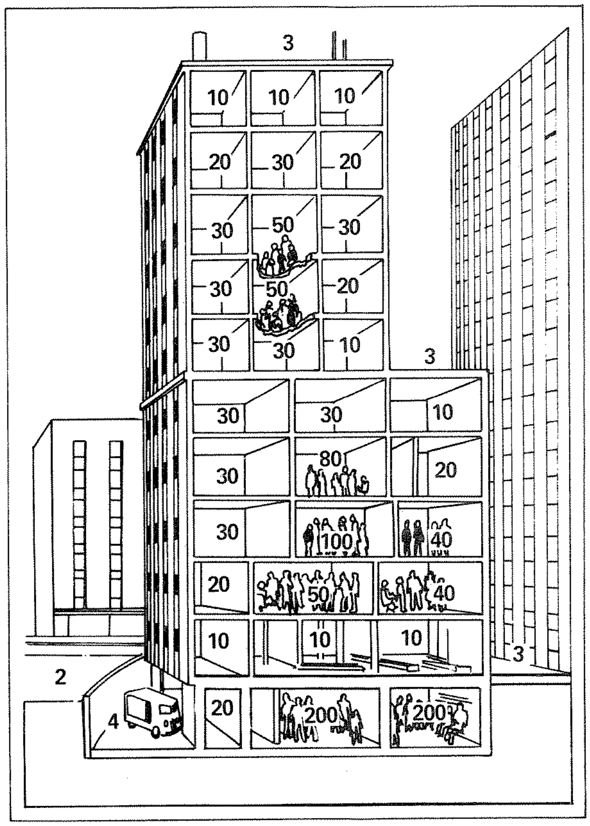
FALLOUT PROTECTION FACTOR

The two previous panels have emphasized that fallout radiation exposure rates will vary from place to place within a relatively small area, especially in urban areas, because of the variable roughness of surfaces, the shielding afforded by nearby buildings, and the action of the wind and rain. It is for this reason that fallout patterns used in peacetime vulnerability analyses and in training courses are defined for an imaginary standard surface; namely, a mathematically smooth, infinitely large, absolutely plane (flat) surface. Real situations are approximated by what is called a "protection factor" (PF).

The fallout PF is an estimate of the ratio of the fallout exposure rate that would be measured at a height of 3 feet above the imaginary standard surface to the exposure rate that could be expected in a given location in the "real world," assuming the uniform deposit of the same amount of fallout material in both cases. Thus, when we noted that measured rates in the open would be 40 percent to 70 percent of what would have been measured over the standard surface, we were also saying that the outside protection factor would very from about 1.4 to 2.5; that is, the hypothetical rate over a smooth infinite plane would be 1.4 to 2.5 times higher than that observed over real surfaces in the actual operating situation. (The action of wind and rain would generally further increase the fallout PF except near "hot spots" or concentrations of fallout, where it would be reduced.)

The most common use of the fallout protection factor is to give a measure of the amount of protection against fallout radiation afforded by buildings and other shelter areas, as shown in the upper sketch. Since these protection factors are all keyed to the standard smooth infinite plane, the PF does <u>not</u> represent the ratio between the exposure rate outside the building to that in the shelter area. Nonetheless, the protection factor is very useful in locating, in advance, the best available shelter from fallout radiation. It is, however, a planning--not an operational tool.

The fallout protection factors in various parts of larger buildings have been calculated from building data collected in the National Facility Survey (NFS). These calculations were preformed on a computer using relationships derived from radiation penetration theory that describe how gamma radiation from fallout-contaminated surfaces is reduced in intensity as it passes through walls and floors (mass or barrier shielding) and through air (distance or geometry shielding). The calculations have been checked by many full-scale and model experiments, of which one is shown in the lower photograph. Here a model building with measuring devices inside was exposed to radiation from a radioactive capsule that traveled around and around through the plastic tubing, thus simulating fallout on the ground.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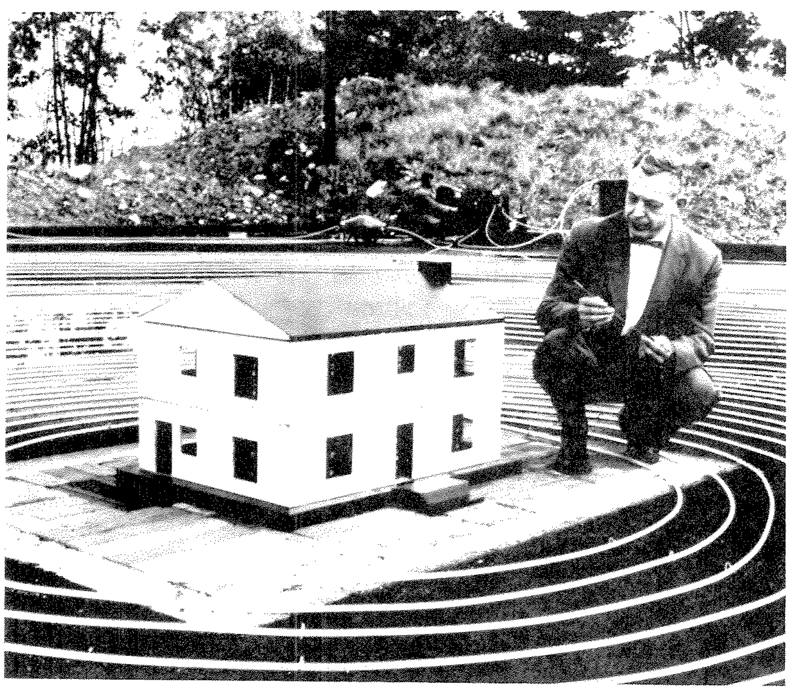


PANEL 18

PROTECTION AGAINST FALLOUT RADIATION

Once more, we show the table of relative blast protection given in chapter 2. We used this table in chapter 5 to show how the protection afforded against initial nuclear radiation compared with the inherent relative blast protection. Here we have added in parentheses the typical range of fallout protection factors that could be expected in the locations described. As before, a high fallout protection factor means good radiation protection.

The lower of the numbers in each parentheses relates to locations near entrances, windows, and the outer portions of aboveground floors; the higher number pertains to locations remote from openings and in core areas. In aboveground locations, the topmost floor will also offer less protection because of fallout material deposited on the roof. Data for each floor, showing protection factors and shelter areas, are available for NFS buildings that have been surveyed for fallout protection.

Recall that protection factor calculations for buildings assume that fallout material is deposited uniformly on ground and roof surfaces. The shielding effect of nearby buildings is taken into account, but the movement of fallout by wind and rain is not. The effect of building damage by blast also is not considered. These effects are highly variable. This is an important reason why radiation measuring instruments should be provided in large shelters to permit the occupants to locate those areas having the lowest exposure rates in the actual fallout situation.

One point to note in this table is that the middle floors of tall buildings offer good fallout protection mainly because they are remote from both the fallout on the ground and that on the roof. These areas do not offer good protection against blast and initial nuclear radiation. In localities that are unlikely to experience direct effects, this fallout protection is a valuable resources for planners.

TYPICAL FALLOUT PROTECTION FACTOR RANGES
RELATIVE TO INHERENT BLAST PROTECTION

Description

1. Special facilities (Mine, Cavern, Cave, Tunnel, Subway, etc.) (1000-10,000)

2. Basement(s) of large structures where the basement overhead floor system is other than wood, flat plate, or flat beam. (100-1,000)

3. Basement(s) of wood frame and/or brick veneer structures. Includes residences. (10-50)

4. First story, second and third story of "strong walled" structures, and no single story has a "side" with 50% or more apertures. For buildings with three or less stories, the topmost story is automatically eliminated. (20-80)

5. Basement(s) of structures where the basement overhead floor system is flat plate or slab supported by a flat beam. (100-200)

6. First three stories of buildings with "strong" walls, less than ten aboveground stories, and greater than 50% apertures; or first three stories of buildings with "weak" walls and less than ten aboveground stories. (20-80)

7. All aboveground stories of buildings having ten or more stories. Fourth through ninth stories of buildings having "weak" walls. (20-100)

8. No blast protection in aboveground stories, i.e., wood frame structure, weak exterior walls, excessive apertures. (Less than 10)

HOW MUCH FALLOUT PROTECTION IS NEEDED?

In panel 15, we showed how much protection shelters having fallout protection factors of 15 and 40 have 30 miles directly downwind of the 500 KT surface burst. To measure the usefulness of the fallout protection factors shown in the previous panel, we need to consider the needs in the areas of more moderate fallout as well. We should also consider how fallout patterns might overlap and build up when many weapons are detonated in an area. The results shown on this chart consider the exposures resulting from a major attack such as with the enemy arsenal described in chapter 1.

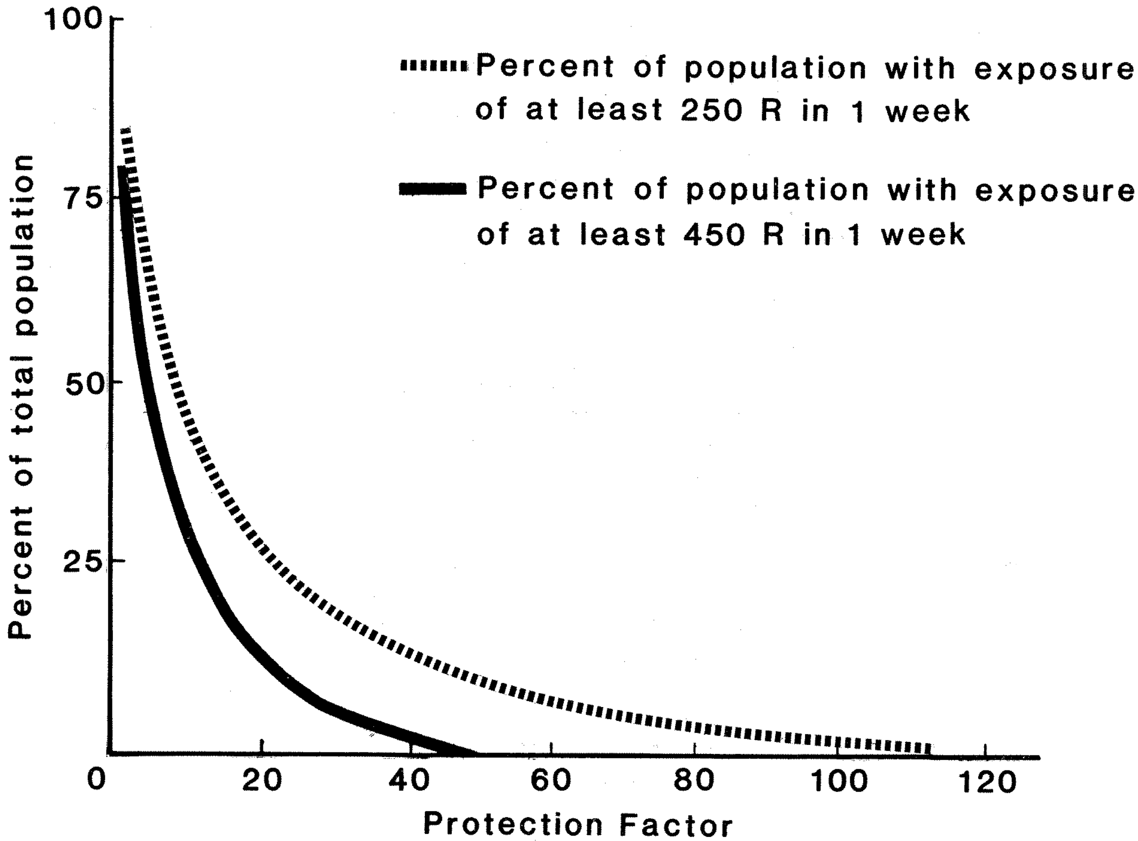
As a starting point, consider the population as if they were all located outside (or in small wood-frame residences) during the first week after attack. We found in panel 16 that the "real world" outside fallout exposure rate was about half of the smooth infinite plane rate, or equivalent to having a PF of 2. For this condition, the dashed curve indicates that about 80 percent of the population of the U.S. would receive a 1 week exposure in excess of 250 R; alternatively, only 20 percent would have received an exposure less than 250 R. Only 25 percent of the population would have a better than even chance of surviving, since 75 percent would have received an exposure in excess of 450 R.

The efficacy of higher fallout protection factors is dramatic. At a PF of 20, 75 percent of the population would receive less than 250 R and all but 10 percent would receive an exposure less than 450 R. At PF 40, less than 2 percent would receive a dose of at least 450 R; over 85 percent would receive less than 250 R. At PF 100, less than 2 percent would receive as much as 250 R.

These percentages account for the whole preattack population, and includes those that would most probably have been killed by blast. When one is attempting to build and improve protection capabilities, it is important to establish desired objectives. However, when one is an emergency planner, one needs to plan to use the best shelter available, even if it offers less protection than the desired level. The data shown here demonstrate that fallout protection factors of 20, or even 10, are greatly to be preferred over leaving some part of the population unsheltered.

One final point--the very best fallout protection is really better than the next best. If a PF of 100 keeps most exposures below 250 R, a PF of 100 will keep them below 25 R. Exposures should be kept as low as possible to reduce incidence of radiation sickness and the risk of longer term biological effects, including genetic damage. Refer to panels 3 through 5 in chapter 5 for additional information on the consequences of radiation exposure.

ONE WEEK EXPOSURE AFTER LARGE ATTACK
FOR VARIOUS PROTECTION FACTORS



PANEL 20

PROTECTION IN RESIDENTIAL BASEMENTS

We noted in chapter 2 that home basements could play an important role in improving survival from blast effects. They can also play an important role in providing protection against fallout radiation. In most parts of the country outside of the downtown areas of cities, the amount of fallout shelter identified in the NFS, which is located in large buildings, is insufficient for the population that needs shelter.

About half the homes in the United States have basements; but, as shown on this map, they tend to be concentrated in the northern part of the country. A small proportion of homes have basements in the South, Southwest, and Far West sections. Even these could be of great value if neighbors shared with neighbors. The average residential basement has an area somewhat greater than 1000 square feet. The standard shelter space in the NFS buildings is 10 square feet per person of useable area. The usual emergency housing space allotment in peacetime disasters is 40 square feet per person of useable area. Thus, from 25 to 100 persons could be sheltered in the average home basement, if necessary.

The fallout protection afforded by home basements can be estimated in the following way:

(1) Single-story homes with average basement wall exposures (i.e., aboveground) less than 2 feet will provide at least a fallout PF 20 throughout the basement.

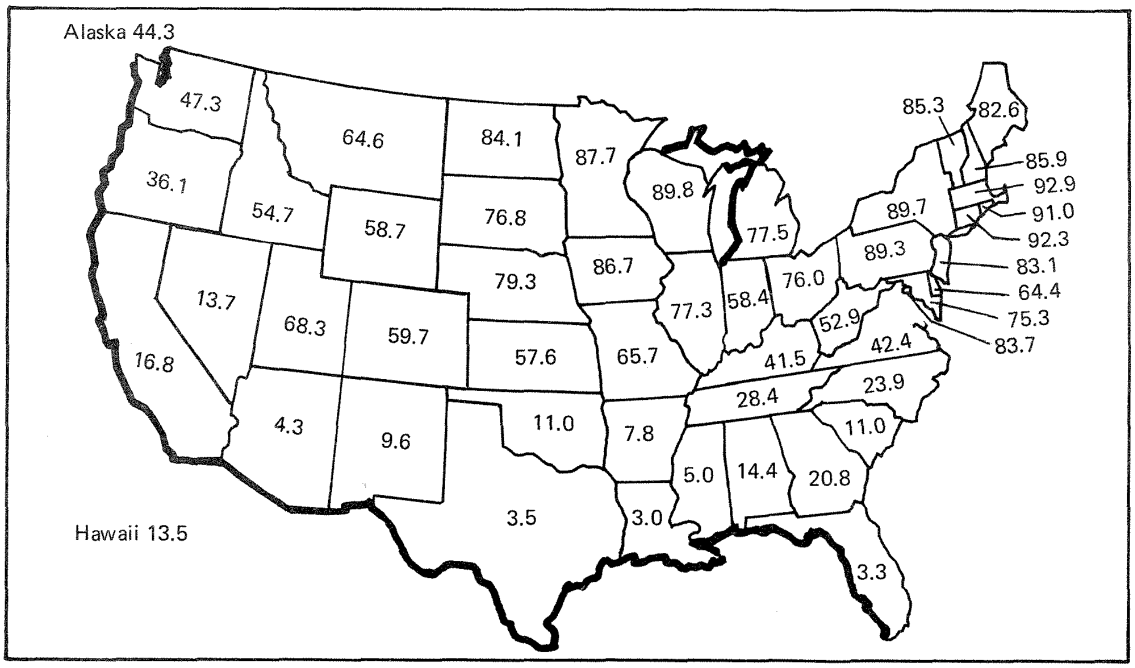
(2) Homes with two or more stories and 2 feet or less average basement wall exposure will provide at least a fallout PF 40 throughout the basement.

(3) Single-story homes with average basement wall exposure greater than 2 feet can be improved to a fallout PF 20 by sandbagging the exposed walls or mounding earth against them.

(4) Similarly, multistory homes with basement wall exposure greater than 2 feet can be improved to a fallout PF 40 by sandbagging or mounding earth.

Generally, fallout protection in home basements is least in the center of the basement and greatest in the corners and along the walls.

PERCENTAGE OF HOMES WITH BASEMENTS



Source: DCPA (BUCENSUS - 1970)

EFFECT OF SIZE OF WEAPON

Throughout this manual, effects have been described mainly for a 500 KT nuclear weapon because it represents the middle range of the current Soviet arsenal. For comparison, we show here the general character of the fallout patterns from 200 KT and 1 MT surface bursts as well. This approximates the yield range of current Soviet missile warheads. (See chapter 1.)

Shown are the maximum exposure rates that would be observed by measurements taken at 3 feet above a smooth, infinite plane. As we saw in panel 16, the actual rates would be less than shown here by a factor of 2 or perhaps more because of the roughness of the surfaces on which fallout had deposited, as well as the limited extent of these surfaces. Also shown, by curved vertical lines, is the time after detonation, in hours, at which the rate would attain its maximum value (assuming a uniform wind speed of 15 mph).

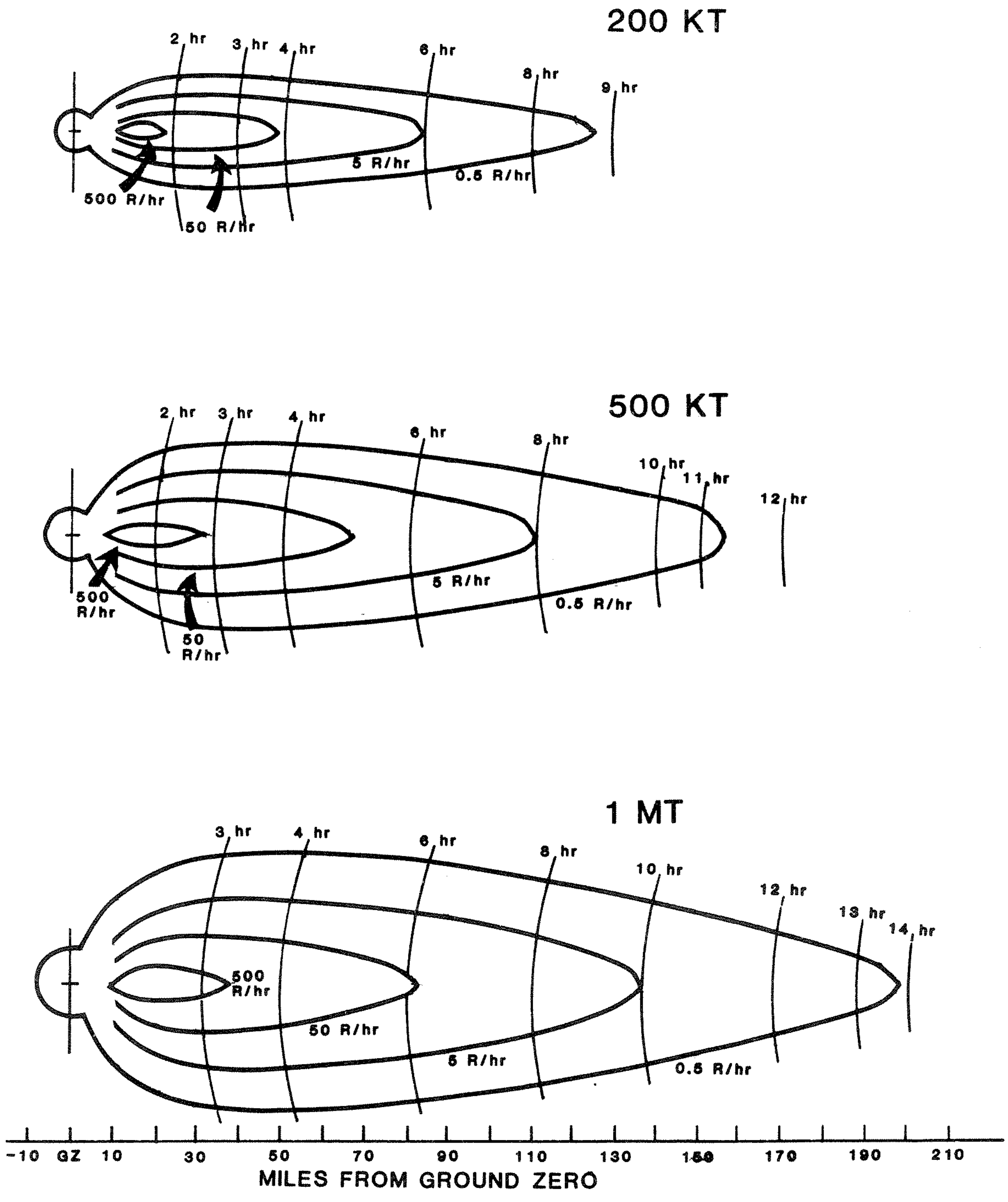
The fallout pattern for a 1 MT surface burst is about twice as wide as that for a 200 KT detonation. It is about 1.6 times as long. The 500 KT pattern is intermediate in size. The highest exposure rate in the downwind area (within the 500 R/hr contour) varies by about the same factor. For a 200 KT burst, the most severe fallout situation in this area has a maximum exposure rate in the neighborhood of 600 R/hr. For the 1 MT burst, it is about 1000 R/hr. As we have seen, the maximum for a 500 KT burst is about 700 R/hr.

The fallout process occurs most rapidly for the smallest weapon yield. Fallout deposited later than about 14 hours after detonation of a 1 MT weapon would not produce an exposure rate exceeding 0.5 R/hr on a smooth, infinite plane. In contrast, significant fallout from a 5 MT weapon may continue to arrive for about a day.

Note that the point 30 miles downwind, used as an example in previous panels, is always in or just downwind of the heaviest fallout area. As the weapon size increases, fallout at this point arrives earlier and ceases later. Shown here are the times of fallout cessation (peak exposure rate). At 200 KT, the peak at 30 miles occurs about 2 1/4 hours after detonation. At 500 KT, the peak occurs at about 2 1/2 hours. At 1 MT, 2 3/4 hours elapse before the maximum exposure rate occurs at 30 miles downwind.

It is pointed out again that these patterns have been derived from a theoretical model of the fallout phenomena.

FALLOUT PATTERNS
(Peak exposure rates and time of peak)
FOR 15 MPH EFFECTIVE WIND



Source: Reference 12

EFFECT OF WINDS

To this point, we have presented fallout patterns for a very simple wind condition; namely, winds at all altitudes blowing from west to east at an effective velocity of 15 miles per hour. Shown here is the fallout pattern from a test detonation of about 5 megatons in the South Pacific (Eniwetok Proving Grounds). Shown are the contours for exposure rates at H + 1. As discussed in panel 14, these are therefore "fictitious rates" because fallout deposition is not complete for many hours after the detonation in most of the area.

The winds in this case were quite variable, blowing in differing directions and speeds at various altitudes up to the top of the mushroom cloud. Nonetheless, the features we have described are still discernible. One can note the stem fallout area around the burst point and the downwind peak area about 35 to 60 miles north. The heavier fallout particles appear to be influenced mainly by lower altitude winds bowing from south to north, while smaller particles also appear to be influenced by winds from east to west at higher altitudes.

In general, winds over the United States are not as complex as those affecting the fallout pattern shown here. Nonetheless, simple, regular, "cigar-shaped" patterns would be extremely unlikely. Very generally, wind speeds increase with altitudes up to the upper troposphere, where a "jet stream" having wind speeds of 50 to 150 or 200 miles per hour often exists over parts of the country. Average wind speeds from the surface to the top of the mushroom cloud vary widely but can range from around 5 miles per hour in the summer to around 40 miles per hour in the wintertime. The effective wind speed used in this chapter, 15 miles per hour, can be considered near the average. Higher wind speeds elongate the fallout pattern, with a corresponding reduction in width.

Because of the thinness of the atmosphere, fallout particles fall faster in the upper altitudes than they do near the earth's surface. Winds from the surface to, say, 5000 feet thus play an important role in the spread of fallout. These winds are affected by terrain and surface temperatures. For example, near-surface winds tend to flow up valleys in daytime and down valleys at night. Onshore and offshore winds in coastal areas are another case in point.

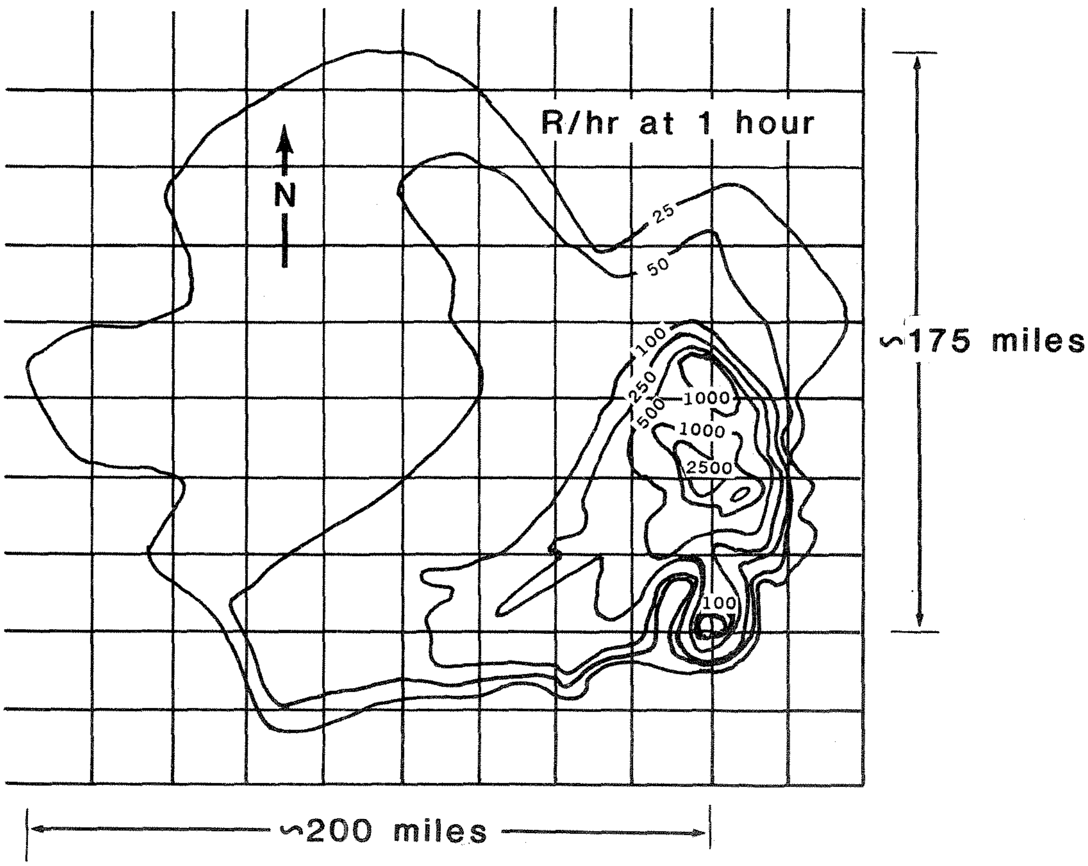
The implications for planning are:

(1) Fallout predictions based solely on wind data are not likely to be accurate in the early hours after detonations. The most reliable indicators of potential fallout arrival are actual fallout measurements reported from locations 20 to 40 miles away.

(2) The fallout "front" will move relatively slowly, from 5 to 40 miles per hour.

(3) Plans to move people from the presumed path of fallout are not practical.

FALLOUT PATTERN FROM A
WEAPON TEST OF ABOUT 5 MT



Source: Reference 1

SKIN BURNS FROM FALLOUT

The fallout discussed thus far has emphasized the gamma radiation emanating from deposited fallout particles, which is the chief threat to survival outside the direct effects area. Another potential source of injury is from the beta radiation also given off by the fallout particles. Beta radiation was described in panel 2. Because it is not very penetrating, beta radiation becomes a potential hazard when fallout is lodged on the skin or lightweight clothing. In close proximity to the skin, the beta radiations are absorbed in the growing layers, causing burnlike lesions if present in sufficient quantity for a sufficient interval of time.

In 1954, residents of Rongelap Atoll in the Marshall Islands were exposed to fallout that arrived 4 to 6 hours after a test detonation on Bikini Atoll about 100 miles to the west. Fortunately, they were located near the edge of the fallout pattern, where they received only about 175 R (gamma) during the 2 days before they were evacuated. About two-thirds of the people experienced nausea and loss of appetite and a few vomited and had diarrhea. Otherwise, the signs of injury from gamma radiation exposure were only disclosed by blood tests, which showed a gradual return to normal.

Nearly all of the people experienced itching and burning of the skin during and after the time fallout was being deposited. They were, of course, lightly dressed. About 2 weeks after exposure, beta burns appeared on the skin, largely on parts of the body not covered by clothing. One such case is shown here. About 90 percent of the people exposed on Rongelap had these burns, and a smaller number developed spotty loss of hair from the scalp. Most of the burns were superficial. Rapid healing occurred in these cases. Some burns were deeper and more painful. A few burns became infected and had to be treated with antibiotics. For the most part, burns had healed and hair grown back by 6 months after exposure.

Experiments and calculations show that "beta burns" are likely only if fallout is deposited on the skin during the first day or two following detonation and mainly during the fallout event itself. Emergency operations after cessation of fallout (peak exposure rate) would not generally result in significant contamination of people. Handling of contaminated objects without gloves would be the principle hazard.

An implication for operational planning is that it would be unwise to delay sending people to shelter until fallout is first detected. A person traveling on foot to shelter at our example point 30 miles downwind of a 200 KT detonation would receive about 20 roentgens in the first 15 minutes after fallout arrival. The person would also have accumulated fallout particles on the scalp, collar or neck area, belt, and shoe-top area that could cause painful burns and possible infection if not removed promptly.

BURN FROM BETA RADIATION

Source: Reference 11

CONTAMINATION OF WATER AND MILK

The 64 Marshallese on Rongelap Atoll were not aware that they were being exposed to fallout radiation, nor of its significance. They remained out of doors and took no special precautions. They continued to drink water from cisterns that received rain water from roofs, and they ate food which had been contaminated with fallout particles. It even tasted gritty. Analysis of urine samples taken after the people were removed from the island showed internal absorption of radioactive materials. The body levels were most serious for two radioactive materials, strontium and iodine. At the time, the estimated concentrations were believed to be too low to result in any serious effects. Body levels fell rapidly; by 6 months radioactivity in the urine was barely detectable. To this day, the general health of the exposed adults has been good and about the same as that of the unexposed population, but nearly all children have suffered serious thyroid injury.

Radioactive elements follow the same metabolic processes in the body as chemically similar stable elements. Thus, strontium, which is chemically like calcium, is deposited in the bone where it can irradiate the blood-forming cells of the bone marrow. Young growing bones incorporate calcium more rapidly than adult bones. Iodine, on the other hand, is absorbed in the thyroid gland. It is estimated that the thyroids of adults received about 160 rads (1.6 Gy) from the absorbed radioiodine. (The rad is a unit of absorbed dose used for both beta and gamma radiation. The Gray, Gy, is the modern SI (Le Systeme International d'Unites) unit for absorbed dose. 1 Gy = 100 rads.) The smaller thyroid glands of the young children, however, received an estimated 525 to 1225 rads (5.25 to 12.25 Gy) from the radioiodine. (Children's exposures after Chernoble were estimated to be only 1/20 as much.)

In 1963, 9 years after exposure, a thyroid nodule was first detected in a 12-year-old girl (who was 3 at the time of exposure). Since then, thyroid abnormalities, many requiring surgery, have appeared in nearly all of those who were less than 10 years of age when exposed. Retardation in growth of the children has also been observed, which has been corrected by thyroid hormone treatment. One example is shown here. These findings indicate the seriousness of ingestion of radioactive iodine. Because of the short half-life of its major isotopes, the iodine hazard would exist, at most, for a month postattack. It is an important hazard as a contaminant in water and milk, especially to the very young.

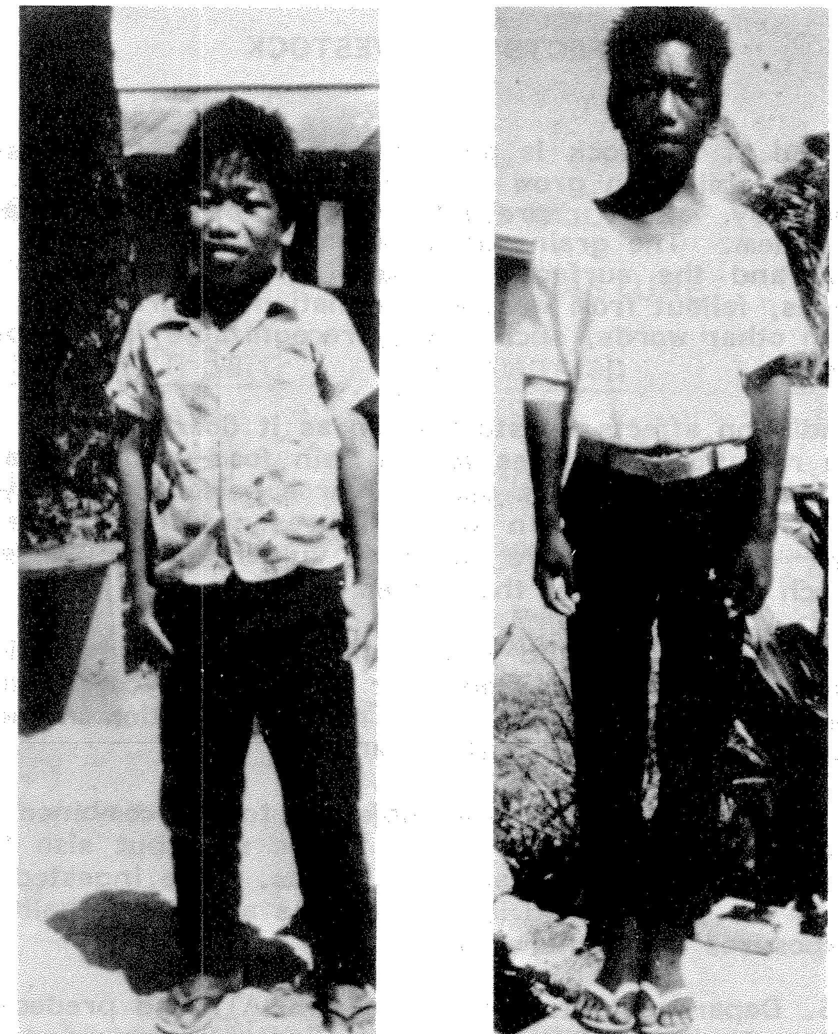
The implications for operational planning are:

(1) Water from sources <u>other than</u> open reservoirs should be used during the first month postattack, if possible;

(2) Young children should not be fed milk from cows that have grazed on contaminated pasture during the first month;

(3) Stocking shelters with "prewar" water can help avoid the iodine hazard; and

(4) Consideration should be given to the stocking and use of potassium iodine (KI) tablets for blocking the uptake of radioiodine by the thyroid.



One of the two boys showing most retardation of growth with development of hypothyroidism. Left: near the beginning of thyroid hormone treatment (1966, age 13); right: after 3 years of treatment (1969), showing remarkable spurt in growth and development with disappearance of hypothyroid symptoms.

Source: Reference 10

PANEL 25

EFFECTS ON LIVESTOCK

The survival of livestock is an important element of an assured food supply, as is the ability to grow crops. The contamination of food other than fresh milk by fallout represents, on the other hand, a relatively unimportant problem. The grains of fallout are readily removed from cans, food packages, and the surfaces of fruits and vegetables by wiping or rinsing. Besides, fallout from weapons detonations is gritty and makes food unpalatable. In other words, such readily recognizable fallout contamination can be dealt with.

Fallout radiation affects livestock much as it does people. Shown here are the gamma radiation exposures to the main food-producing animals that would result in about 50 percent deaths over a period of 60 days following exposure. The first column (In Barn) represents the effects of gamma radiation only. Most animals are about as vulnerable as people, although poultry are much more resistant than other animals.

Animals in open pens would receive not only gamma radiation but also skin burns from fallout deposited on their backs. The combined effect has been accounted for (second column) by a modest reduction in the amount of gamma exposure required to kill half the animals.

Finally, animals on pasture are subjected to the combined effects not only of gamma radiation and beta burns to the skin but also the internal injury resulting from eating contaminated grass. The ingested fallout can cause damage to the stomach and intestines. As a result lethality occurs at much lower exposures than otherwise.

The U.S. Department of Agriculture (USDA), and predecessor agencies of the Department of Energy and the Federal Emergency Management Agency joined in sponsoring research on livestock effects and protection for a number of years. The information shown here suggests the sort of actions that should be planned to preserve this valuable food resource. Local planners can get more details from their USDA County Emergency Board Chairman and the county extension agent.

EXPOSURE IN ROENTGENS, TO KILL HALF THE ANIMALS
IN BARNS, PENS, OR PASTURE

Animal	In Barn (R)	In Open Pen (R)	On Pasture (R)
Cattle	500	400	170
Sheep	400	320	240
Pigs	660	(550)*	(400)
Horses	670	(600)	(350)
Poultry	850	(780)	(730)

*Parentheses indicate no experimental data available

Source: Reference 6

EFFECTS ON CROPS AND CROPLAND

Not too many years ago it was believed that, following a nuclear attack, large areas of vulnerable farmland would have to be abandoned for generations because of fallout contamination. This view was based on early estimates of the availability of radioactive strontium in soluble form and the amount that would be taken up by the roots of growing plants. As explained in panel 6, we now know that radioactive strontium is depleted in heavy fallout areas; and, moreover, most of the radioactive material is locked within the glassy particles. In addition, it has been found that crops in the open field do not take up strontium as readily as was assumed. Thus, even though radioactive strontium has a long half-life (about 28 years), crops grown the year following an attack except in areas which had received very heavy fallout deposits, radiation exposure to farm workers would no longer be of consequence.

On the other hand, the yield of growing crops can be severely reduced or the plants killed by the levels of gamma radiation to be expected over wide areas following nuclear attack. Gamma doses that would reduce crop yield by 50 percent on the average are shown here for some important food and forage crops. Beta radiation from fallout particles adhering to various parts of the plant or on the ground will add to the dose, amounting to 1 to 20 times the gamma dose depending on the crop and stage of growth. Young, actively-growing plants are most vulnerable; those near maturity are least vulnerable. Severe damage to crops may therefore be expected where the gamma 1-week dose is only a few hundred to a thousand or so roentgens.

Much more can be said about the expected effects of gamma radiation on plants than about the expected effects of beta radiation. Consequently the ability to predict injury to plants from fallout is unsatisfactory and probably will remain so. There are two reasons: first, far more experimental work has been done with gamma radiation; and second, the damage from beta radiation depends critically upon how much and how long the fallout remains on the sensitive parts of the plants and this is subject to unpredictable wind and rain effects. This situation is of operational significance in agricultural areas if one is to avoid committing manpower and scarce fuel and fertilizer to the growth of crops that have already been injured beyond the point of economic yield. As information in this area is gained, it will be made available through the USDA County Emergency Boards and the county extension agents.

GAMMA DOSE IN ROENTGENS TO REDUCE CROP YIELD BY 50 PERCENT

Crops	YD-50 Dose (R)
Peas, Broadbeans	Less than 1000
Rye, Barley, Onion	1000 to 2000
Wheat, Corn, Oats, Cucumber	2000 to 4000
Peanut, Alfalfa, Fescue, Sorghum	4000 to 6000
Cotton, Sugar Cane, Melons, Celery	6000 to 8000
Soybeans, Beets, Broccoli, Red Clover	8000 to 12,000
Rice, Turnips, Sweet Potatoes, Strawberries	12,000 to 16,000
Squash	16,000 to 24,000

Source: Reference 4

EFFECTS ON THE HUMAN ECOSYSTEM

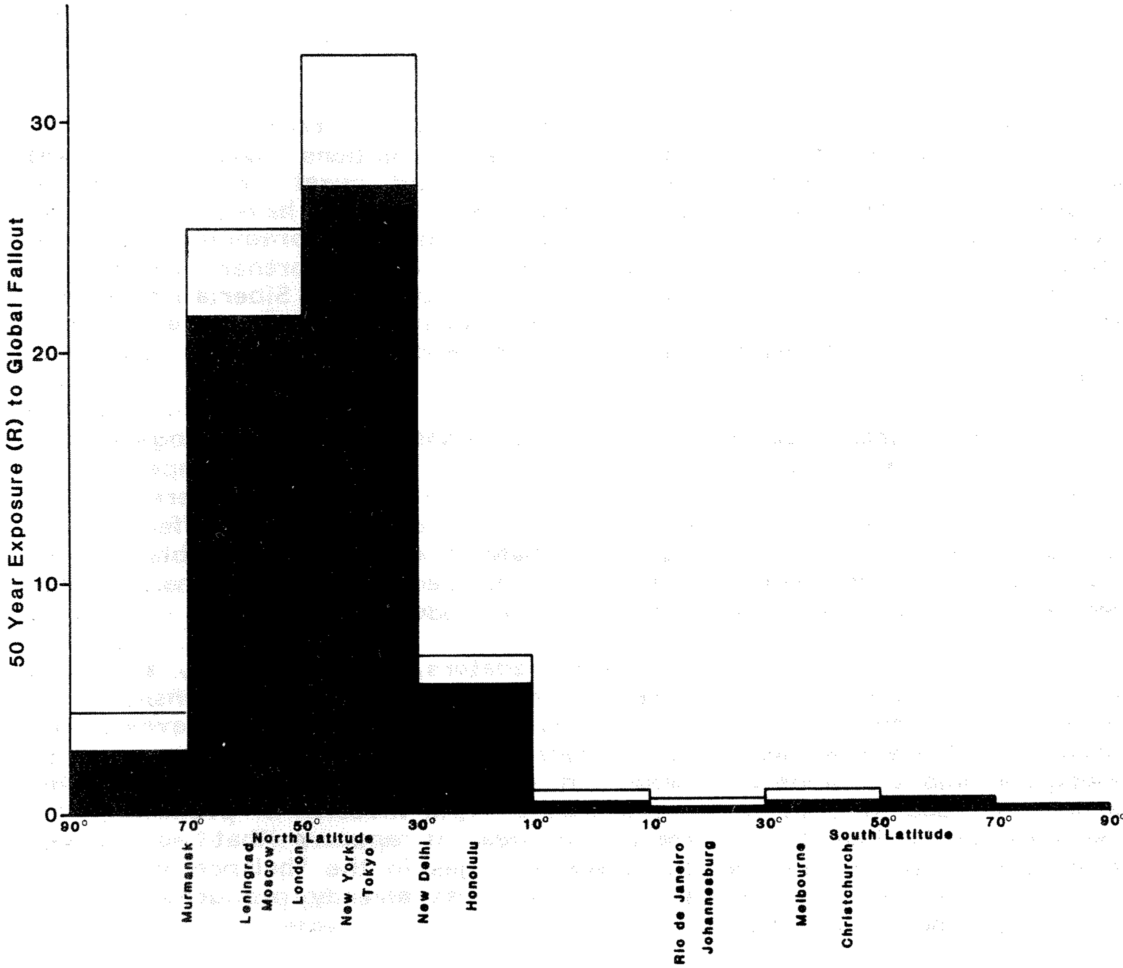
The study of the interrelationships among members of a community of animals and plants is called ecology. The community itself, including its physical environment, is usually referred to as an ecosystem. Concern has been expressed since the development of nuclear weapons that a nuclear war might have a catastrophic effect on the biological environment.

In the novel On the Beach, the author, Neville Shute, had to invent an impossible kind of fallout to cause the end of mankind. This fictional fallout did not settle out or undergo significant radiological decay. Others, not intending fiction, have forecast a new Ice Age or the opposite, the melting of the polar ice caps, raising the level of the oceans to flood most of the populated part of the world. In late 1982, articles began to appear in the media and quasi-scientific journals using a very simplified analysis of the atmosphere and employing questionable assumptions about both the fallout and smoke particles which could be produced from fires. Their projections have been called "nuclear winter," and to it was ascribed the destruction of crops, certainly in the northern hemisphere and quite possibly around the globe.

Still other calculations indicated that radiation from widespread fallout could threaten to produce "hot spots" with long term (50 year) total exposures of 100 R or larger. The problem is that of "global fallout," i.e., fallout that has penetrated to and into the stratosphere and thus is above the normal weather factors that assist gravity in bringing down the early (within 24 hours) fallout. Tropospheric fallout descends to earth in a matter of months. Stratospheric fallout may continue over a period of years. While these phenomena were recognized in the 1950's it was not until the 1970's that the climatological models and high speed computers were available and applied to the study of "delayed" fallout. Using worldwide data from the nuclear tests of the mid-1950's, analysts applied sophisticated global models to war scenarios involving exchanges of nuclear weapons. An output of one study is shown on the opposite panel.

The panel depicts the exposure to global fallout over a 50 year period following the exchange. Exposures are given for 20° bands of latitude for both a winter and a summer exchange. It may be seen that the winter exchange produces, in each band, an equal or greater exposure. It is not surprising, given the scene of the conflict, that the maximum exposures occur in the 30° to 50° north latitude band, about 33 R (winter) and 27 R (summer). Southern hemisphere exposures are seen to be less than 1 R.

The exposures predicted are for the idealized case. Given more realistic exposures, say 1/3 of those shown, average exposure in the northern hemisphere would be about 5 R. For comparison, the annual exposure in the U.S. to natural radiation background (cosmic rays, building materials, ground, and internal sources) is about 0.1 R. Over 50 years, this would amount to 5 R. Exposure to manmade radiation sources (medical/dental, past weapon test fallout, releases from coal burning, nuclear power plants, and consumer products) would also total about 5 R over the 50 year period. Hot spots could occur but in them the 50 year exposure would be less than 2 1/2 to 3 times the maximum shown.



Nuclear Exchange in Northern Hemisphere (unshaded - -Winter - - shaded - Summer)

- Number of weapons - 6235
- Total yield - 5300 MT
- Fission fraction - 0.5
- Fraction surface bursts - 0.47
- Fission products injected into the atmosphere - 2031 megatons
- No sheltering, no weathering, smooth planes
- Northern hemisphere average - 16 R
- Southern hemisphere average - 0.6 R

PANEL 28

EFFECTS ON THE GENERAL ECOLOGY

The "doomsday" predictions served to initiate extensive research into not only climatological models but also the assumptions about smoke and dust production, targeting, weapon yields, and burst heights. Within several years the results of this additional research have reduced the "nuclear winter" to perhaps a "nuclear cooling" with predictions of only days or weeks of temperature drops of 10°C or less. Northern hemisphere agriculture would not be wiped out (although Canada and Siberia could have serious problems). Predictions of global fallout exposures were similarly significantly reduced especially for those who used minimal protective actions.

Large volcanic eruptions may offer the closest natural analogy to the prediction of the worldwide dust dispersion and lower temperatures. Indeed, the three major volcanic eruptions in recent history were all followed by exceptionally cold years, but only a single year was affected. It has been concluded that the earth's climate is exceptionally stable despite severe temporary imbalancing effects. Continued pressure of change over decades and centuries would be required to produce an Ice Age.

Similarly, observation that insect predators, such as birds, are more vulnerable to fallout radiation has led to predictions that the insects will inherit the earth after a nuclear war. Analysis shows, however, that heavy fallout areas would be rarely more than 50 to 100 miles from areas of negligible fallout. Since the population of the various species is controlled largely by food supply, there would be a rapid invasion of predators into the temporarily insect-rich areas. In sum, it appears that no nuclear attack can induce gross and permanent changes in the "balance of nature" anything like those that human civilization has already produced through agriculture and urbanization.

On the other hand, there could be ecological changes that might require governmental control action in the early postwar years. Worldwide fallout could increase rainfall over normal amounts by acting as a "cloud-seeding" mechanism. This would have adverse effects in flood plain areas but would delay the onset of fire hazard from radiation-killed trees in areas of moderate-to-heavy fallout. Failure to log dead trees (which would be useful for housing and firewood) would sooner or later result in forest fires and erosion. Over a period of several years, silting could destroy the usefulness of reservoirs and irrigation works. Finally, degraded sanitation and public health measures in damaged urban areas could create conditions favorable to outbreaks of disease-carrying insect and rodent populations. All these consequences, however, are subject to human planning, intervention, and control.

IMPLAUSIBLE CATASTROPHES

1. End of all life on the planet Earth.
2. A new Ice Age.
3. Nuclear Winter.
4. Melting of the polar ice caps.
5. Insects inherit the Earth.

POSSILBE ECOLOGICAL CONSEQUENCES

1. Temporarily increased rainfall.
2. Fire hazard in dead pine forests.
3. Longer term threat of increased erosion and silting.
4. Outbreaks of disease-carrying insects and rodents in damaged urban areas.

PANEL 29

FALLOUT IN THE DAMAGED AREA

Most of the fallout from nuclear detonations is carried tens to hundreds of miles by the wind before it is deposited in the ground. For this reason, we have emphasized the fallout environment outside the area of blast damage and fire. Fallout from surface bursts will also occur in the direct-effects area, making firefighting, rescue, and medical aid more difficult and urgent. The next six panels describe the fallout threat in the damaged area, as defined by the Miller fallout model. Weapons test data supporting these estimates are quite limited.

Fallout does not arrive immediately in the damaged area. Particles begin to fall from the rising fireball when the rate of cloud rise decreases to less than the falling velocity of the particles. The time of arrival of first fallout from the mushroom stem is shown in the table for 200 and 500 KT and 1 MT detonations.

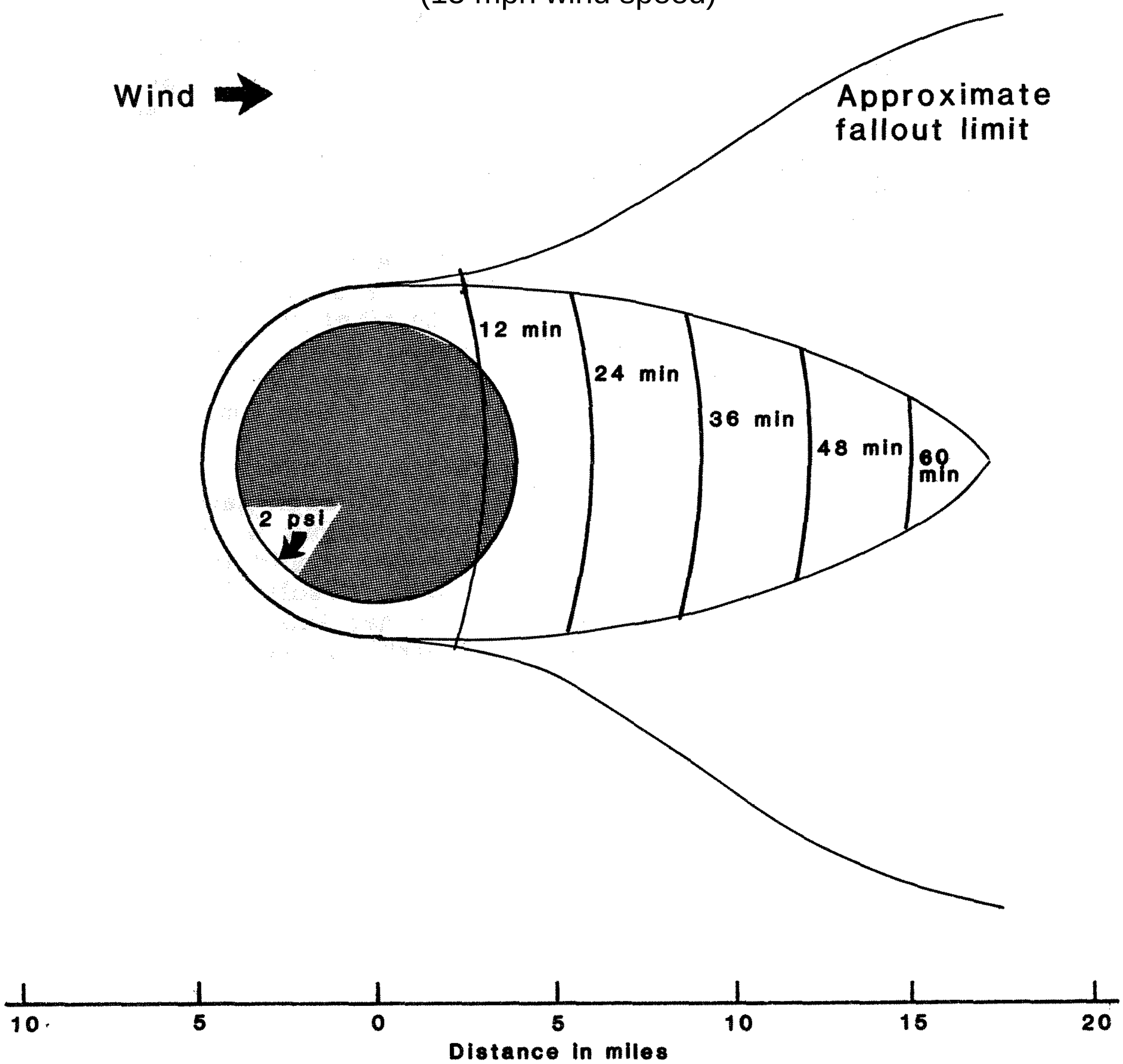
The somewhat complex pattern below the table shows the time of arrival of close-in fallout for the example 500 KT surface burst used previously. Fallout arrives almost simultaneously at 12 minutes after burst over nearly all of the direct effects area. (For reference, the extent of 2 psi blast overpressure is shown as a dotted circle.) Thereafter, fallout progresses downwind at the assumed effective wind speed of 15 miles per hour, reaching a distance of about 15 miles at 1 hour after detonation. For other wind speeds, the distances shown would obviously be different.

One might ask how it could be that fallout would not arrive at 15 miles downwind until 1 hour after detonation when, in panel 9, we saw that fallout arrived 30 miles downwind at 1 hour and 35 minutes after burst. The reason is that the point at 30 miles is in the cloud fallout region, not the stem fallout region. In the upwind portion of the cloud fallout region, fallout from the bottom of the cloud arrives before that from the main portion of the cloud. The earliest arrival of cloud fallout is beyond 30 miles and arrival times increase toward ground zero. Fallout arrival at 25 miles is later than at 30 miles, increasing to about 1 hour inside 20 miles where cloud and stem fallout arrive almost simultaneously. Therefore, stem fallout arrival times are not shown beyond 1 hour.

EARLIEST FALLOUT ARRIVAL

Weapons Yield	Fallout Arrival Time
200 KT	10 minutes
500 KT	12 minutes
1 MT	14 minutes

FALLOUT ARRIVAL FOR 500 KT BURST
(15 mph wind speed)



PANEL 30

EARLY OPERATIONAL EXPOSURES

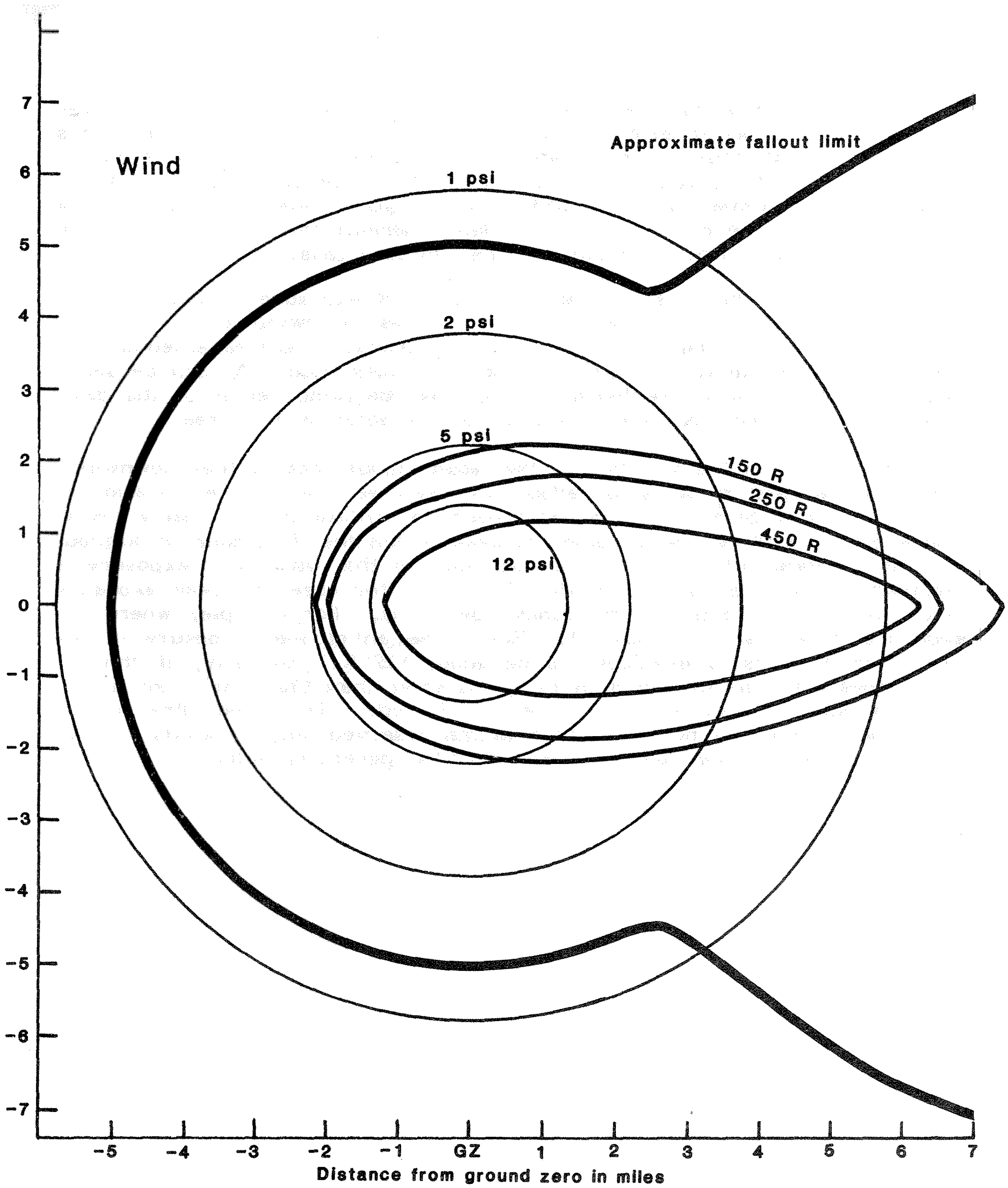
Although fallout will arrive in the damaged area within 10 to 20 minutes after detonation, fallout radiation exposures during the critical first hour will generally be nominal. The region affected by the exposures defined in the Radiation Penalty Table of panel 15 is shown here. This region is confined to a small downwind area in the moderate and severe damage areas. There is a small area astride the 12-psi circle where exposures in the first hour would be in excess of 450 R. Practically all of the area where suppression of smoldering ignitions, firefighting, rescue, and medical aid would be urgent tasks could experience outside exposures of less than 150 R during the first hour.

The exposures shown are not those that would be received over a smooth, infinite plane. As we saw in panel 16, exposures under actual operating conditions would be lower than the smooth, infinite-plane case because real surfaces are rough and of limited extent. Debris caused by blast damage would make most of the damaged area quite "rough." How "rough" these areas might be can be appreciated by reviewing the last several panels of chapter 2.

For this example, it has been assumed that the "real world" exposures would be about one-third those predicted for the smooth, infinite-plane situation. This is probably a conservative estimate of the effect of blast damage, and actual exposures could likely be even lower. Radiation exposures could vary even more widely than suggested by panel 16. To aid in control of such exposures, at least one member of each emergency team should be equipped with a dosimeter.

One additional point to be considered is that, although gamma radiation exposures might be nominal during the first hour, fallout would be occurring during most of this period. Emergency teams should be dressed to avoid accumulation of fallout particles on the skin. A suit giving complete isolation is not necessary. A coat with hood or hat and gloves would be sufficient. The usual fireman's "running gear" is excellent for the purpose.

EXPOSURE DURING FIRST HOUR
(500 KT, surface burst, 15 mph wind)



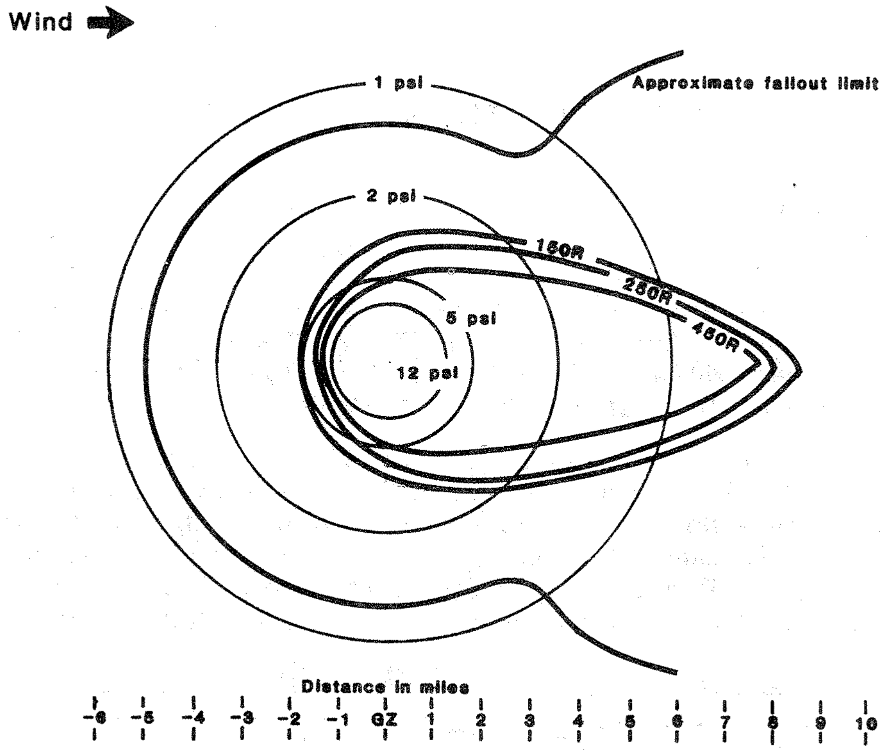
LATER OPERATIONAL EXPOSURES

Urgent tasks of fire defense, rescue, medical aid, and remedial movement of people from threatened shelters may require continued operations beyond the first hour after a detonation. Shown here are the areas in which 150 R, 250 R, and 450 R exposures might be expected during the first 2 hours (upper sketch) and first 4 hours (lower sketch). The assumption as to the roughness of the debris-strewn area is the same as in the previous panel, i.e., one-third of the idealized case.

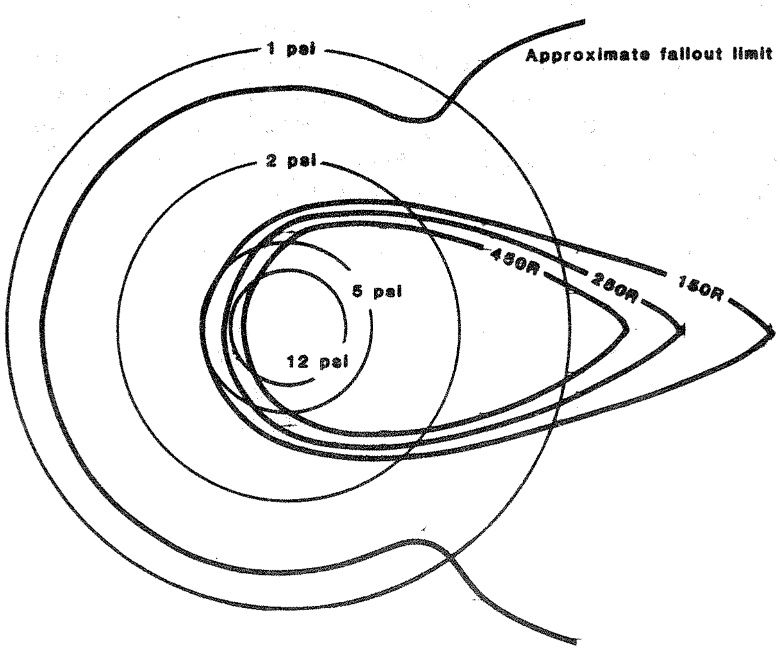
At 2 hours, the area enclosed by the 450 R exposure contour extends from about 1 1/2 mile upwind to about 8 miles downwind and is about 4 miles across at its widest. By the end of 4 hours, this area extends from 1 mile upwind to 10 miles downwind and is 4 miles wide. As can be seen, exposures above 150 R are likely only in the downwind sector of the damaged area and affect less than one-third of the potential fire area.

In contrast to the situation in the cloud fallout area further downwind, the exposure rate in the stem fallout will peak well before the cessation of fallout. This is because of the rapid decay of radioactivity at early times. The exposure rate can be expected to peak within the first hour throughout most of the damaged area. Only a small part of the subsequent exposure is received during the "buildup period." Hence, the observed peak exposure rate can be used to guide emergency operations. For example, where the exposure rate peaks at, say, 125 R/hr, the anticipated exposure in the first 2 to 4 hours is predicted to be about 125 R. Similarly, if the CD V-715 goes off scale on the high range (greater than 500 R/hr), potentially lethal outside exposures are to be anticipated. Since the direction of downwind fallout may not be related to the observed surface winds, use of radiation measurements becomes a necessity in operational activities.

EXPOSURE DURING FIRST TWO HOURS
(500 KT surface burst, 15 mph wind)



EXPOSURE DURING FIRST FOUR HOURS



EFFECTS OF FIRES ON FALLOUT DEPOSITION

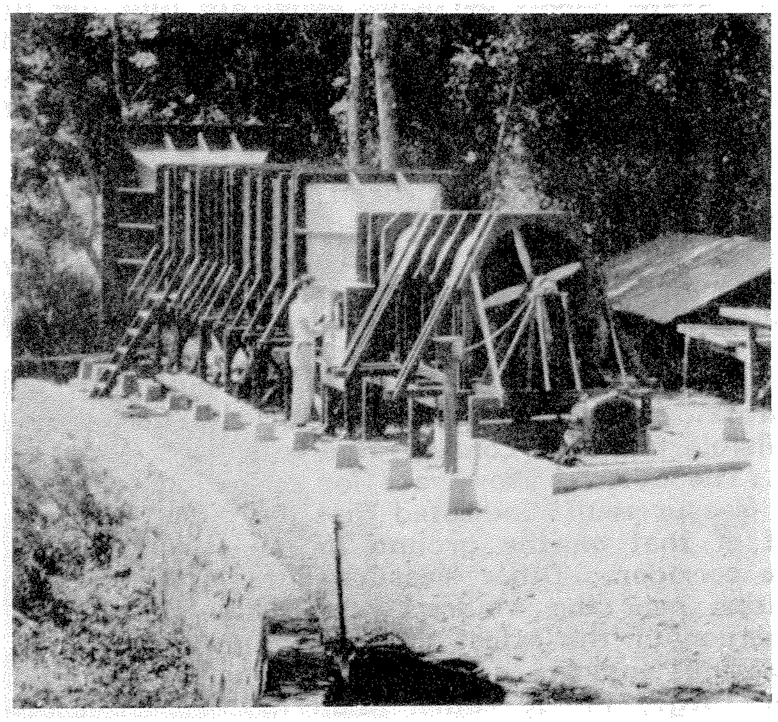
In chapter 3, the fire environment in the damaged area was described. Mass fires are marked by "in-rush" winds and a rising "convection column" above the fires. Theoretical analyses of convection columns above large-scale fires indicate that the updraft from even moderate rates of heat output exceeds the falling velocities of most fallout particles. It would appear, then, that convection columns induced by fires set by the detonation could have an effect on the fallout pattern.

A time lapse occurs between the times of ignitions and the time when massive fires can be burning. Experience from World War II incendiary raids indicates this time period may vary from 25 to 45 minutes. The effect of the nuclear blast wave in suppressing ignitions to a smoldering condition could increase this time delay substantially. Thus, it is unlikely that the fires resulting from a 500 KT yield surface burst would alter significantly the deposition of stem fallout in the damaged area.

Analyses and experiments have been done to assess the effect of well-established fires on fallout deposition from the cloud or from later fallout from upwind detonations. The main experiments were conducted in the low-velocity wind tunnel shown here. Gas burners were used to simulate the fire area and simulated fallout was introduced upwind of the fire near the top of the wind tunnel. As predicted by theory, the fire updraft buoyed up the fallout, causing it to fall much further downwind than otherwise would be the case. There was also much lateral dispersion of the fallout; so the effect would be to lower markedly the high exposure rates in the downwind area and increase somewhat the lower exposure rates over a much larger area.

Other experiments showed that rapidly burning fires in already contaminated areas as small as one-tenth of an acre resulted in removal of perhaps a third of the deposited fallout, and the removed material was dispersed so that there was no significant concentration in any other region. This process may have some effect in further reducing radiation hazards during firefighting operations.

LOW VELOCITY WIND TUNNEL USED
IN FIRE FALLOUT EXPERIMENTS



Source: Reference 7

EFFECT OF DAMAGE ON FALLOUT PROTECTION

The fallout protection afforded by buildings (panel 18) is estimated on the basis that the roof and surrounding ground areas would be uniformly contaminated with fallout and that fallout would not lodge on the sides of the buildings nor would fallout particles penetrate into the interior of the building. In effect, the calculation is made as if the fallout fell vertically onto the surfaces below. In the real world, winds or breezes are blowing near the ground most of the time. If windows were broken or walls blown in, some fallout could penetrate into the interior of buildings.

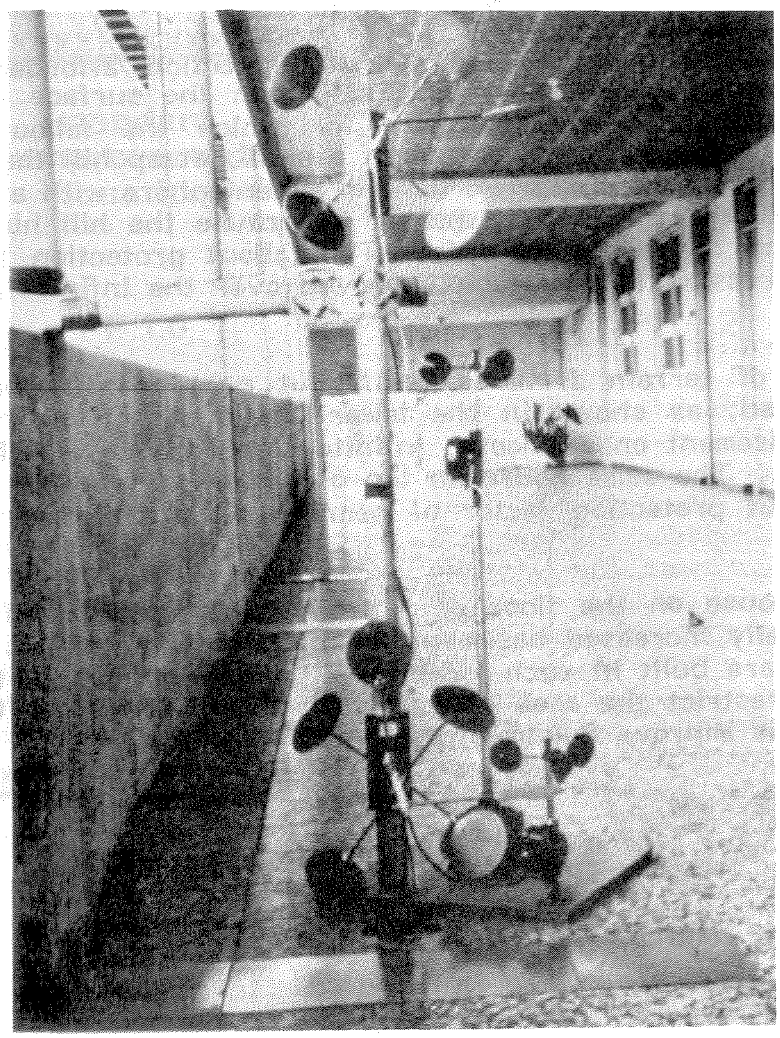
A number of calculations have been made of the effect of "fallout ingress" on the fallout protection afforded by buildings. These estimates have been necessarily highly idealized and are of limited utility. The small amount of experimental evidence available does indicate, however, that large reductions in fallout protection are <u>not</u> to be expected in most instances.

The best evidence comes from the volcano fallout in Costa Rica described in panel 12. Shown here is a fallout situation where most of the wall is open. Visible fallout is concentrated in a band about 20 inches wide below the sill. (The devices shown are for collecting fallout and measuring air movement.) Measurements indicated that the deposition near the sill was about 5 percent of that on the ground on the open and about 1 percent elsewhere in the corridor. Other measurements near smaller open windows indicated deposition near the windows of about 1 percent of the exterior amounts. Calculation of the effect of this amount of ingress on the mid-floors of tall buildings indicate a reduction of about 5 percent in the fallout protection factor (e.g., PF 38 rather than PF 40). Measurements under covered walkways where both sides were completely open indicated that as much as one-tenth of the outside deposit level could be deposited. Thus, where walls are completely blown in as shown in the upper sketch of panel 14 of chapter 2, the fallout protection factor in the middle floors could be reduced by perhaps 10 percent or more (e.g., PF 35 rather than PF 40).

In most cases the deposition of building debris on the floor above basements would tend to increase the fallout protection.

The most serious degradation of fallout protection due to blast damage would occur in residential basements and the basements of other lightly constructed buildings under the circumstance where the building is blown clear of the basement (lower sketch in panel 12 of chapter 2). Fallout would be deposited in the basement, reducing the fallout protection factor from 20 to 40 down to about 4 or 5. It would be necessary for basement occupants to prop sections of flooring or walls against the basement wall, lean-to fashion, and to cover the lean-to with nearby pieces of masonry for fallout protection. This need is another reason why it may be desirable to plan for group occupancy of residential basements in urban areas rather then single families.

OPEN CORRIDOR ON THIRD FLOOR OF SCHOOL
CONTAMINATED BY FALLOUT-LIKE VOLCANIC
DEPOSIT IN COSTA RICA



Source: Reference 9

WHAT ABOUT HILLS?

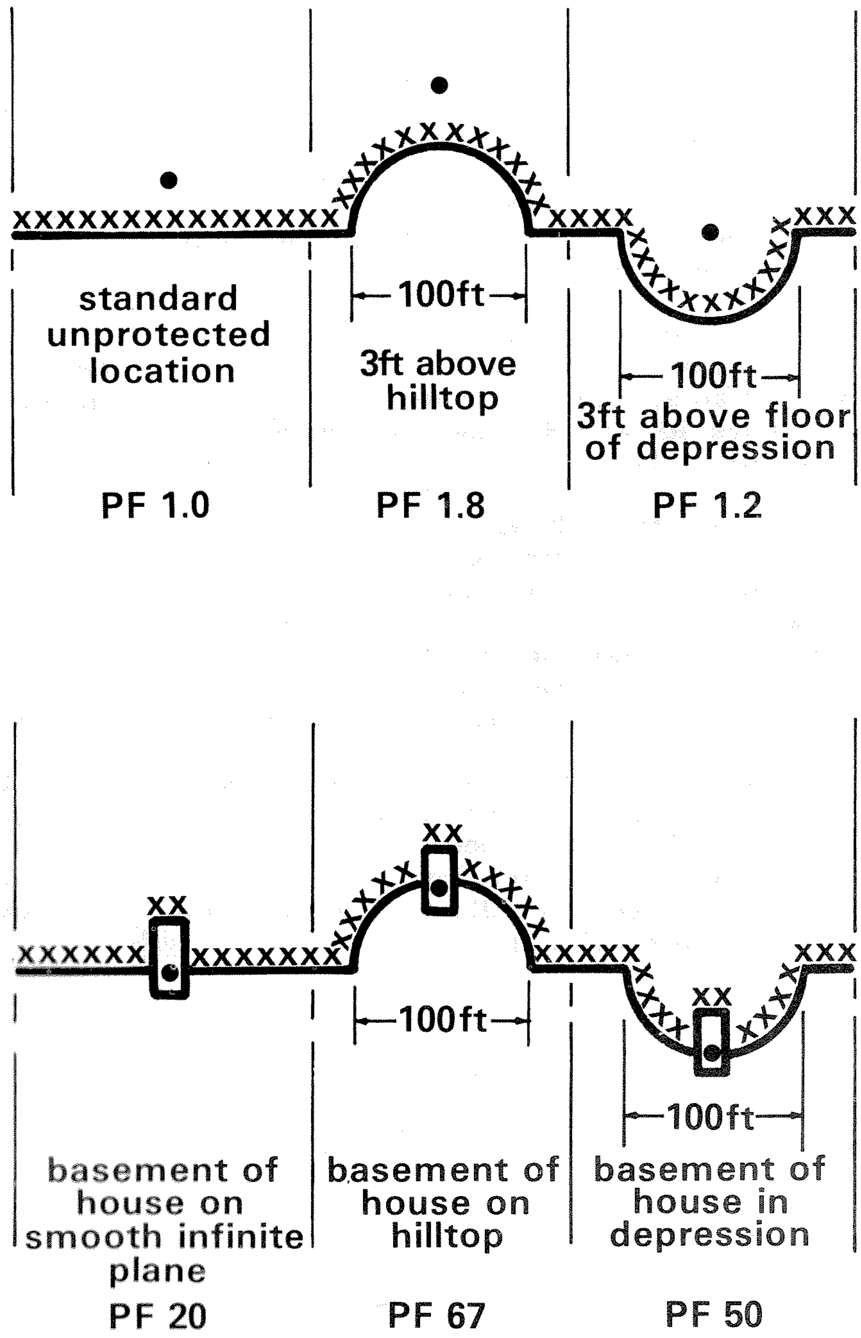
Fallout protection factor calculations assume that fallout is deposited on smooth plane surfaces. In panel 16, the effect of the roughness of real surfaces was discussed, but again in terms of level terrain. The question might be raised as to the effect of prominent terrain features, such as hills and valleys.

The upper sketches show the fallout protection afforded a person standing in the open on smooth surfaces. When the surface is level, we have the standard unprotected location for which the fallout protection factor is 1. If the person were on top of a small, steep hill that falls away in all directions (the example shown here is a hemisphere with a diameter of 100 feet), the PF is increased to nearly 2 because the hill hides much of the fallout beyond the immediate area. The fallout protection factor for a small, steep depression is not much improved over the infinite-plane situation.

The effect of terrain features on fallout protection in basements is much more marked, as shown in the lower sketches. The first situation shows a home basement on a smooth, infinite plane having a fallout protection factor of 20. The same house on top of a small, steep hill would have a basement fallout protection of nearly 70. Many rural houses are built on hills.

The same house on the floor of a small, steep depression would also have a substantially increased basement fallout protection factor. However, not many homes are built in such locations. In general, undulations of the terrain tend to restrict the area of fallout that can contribute to radiation exposure and thus improve fallout protection.

EFFECT OF TERRAIN FEATURES



Source: Reference 14

A NOTE ON DECONTAMINATION

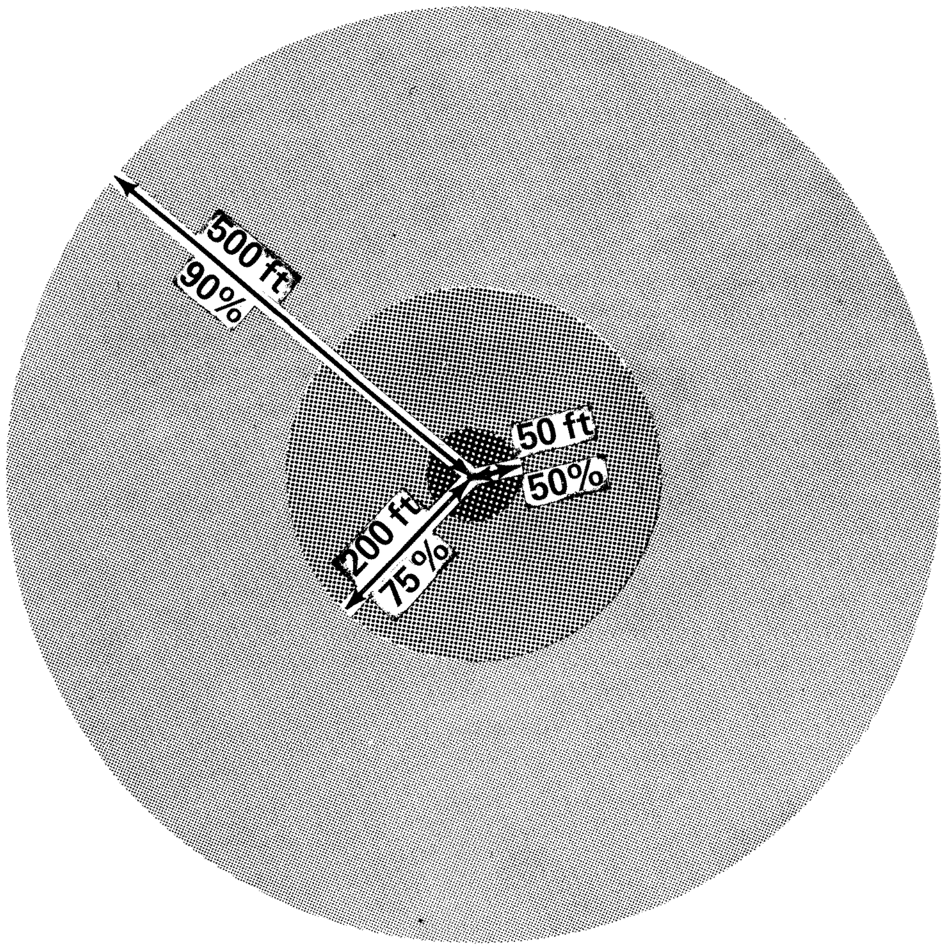
Surfaces on which fallout particles have fallen are called contaminated surfaces. Being sandlike material, fallout can be cleaned from most surfaces by readily available means. The process of removing fallout particles from exposed surfaces and disposing them where they cannot harm people is called radiological decontamination. Paved areas can be decontaminated with firehoses, street flushers, or with street sweepers. Roofs can be decontaminated with firehoses. Unpaved areas can be decontaminated by scraping off or plowing under the top layer of soil.

As shown in this sketch, half of the radiation received at a point 3 feet above a large, smooth, unbroken surface comes from fallout within 50 feet. On rough surfaces, the area contributing half the exposure is much less. In an area covered with 6 inches of debris, half radiation comes from fallout within about 10 feet.

The sketch shows that three-quarters of the radiation comes from fallout within 200 feet on smooth surfaces (100 feet or less on rough or debris-strewn surfaces). But at least 10 percent of the exposure comes from fallout radiation originating many hundreds of feet away. This suggests that, if large reductions of exposure are desired, not only must the work or living area be decontaminated, so must a "buffer zone" around it be decontaminated to a distance of several hundred feet in most instances.

For this reason, decontamination as a measure to improve the fallout protection of people in shelter is not generally practical except, possibly, for the sweeping up of visible fallout near broken windows or near entrances to a shelter area. Decontamination can be important, however, in speeding postattack recovery in fallout areas. Hence, decontamination is covered in more detail in chapter 8.

EXPOSURE CONTRIBUTION vs DISTANCE

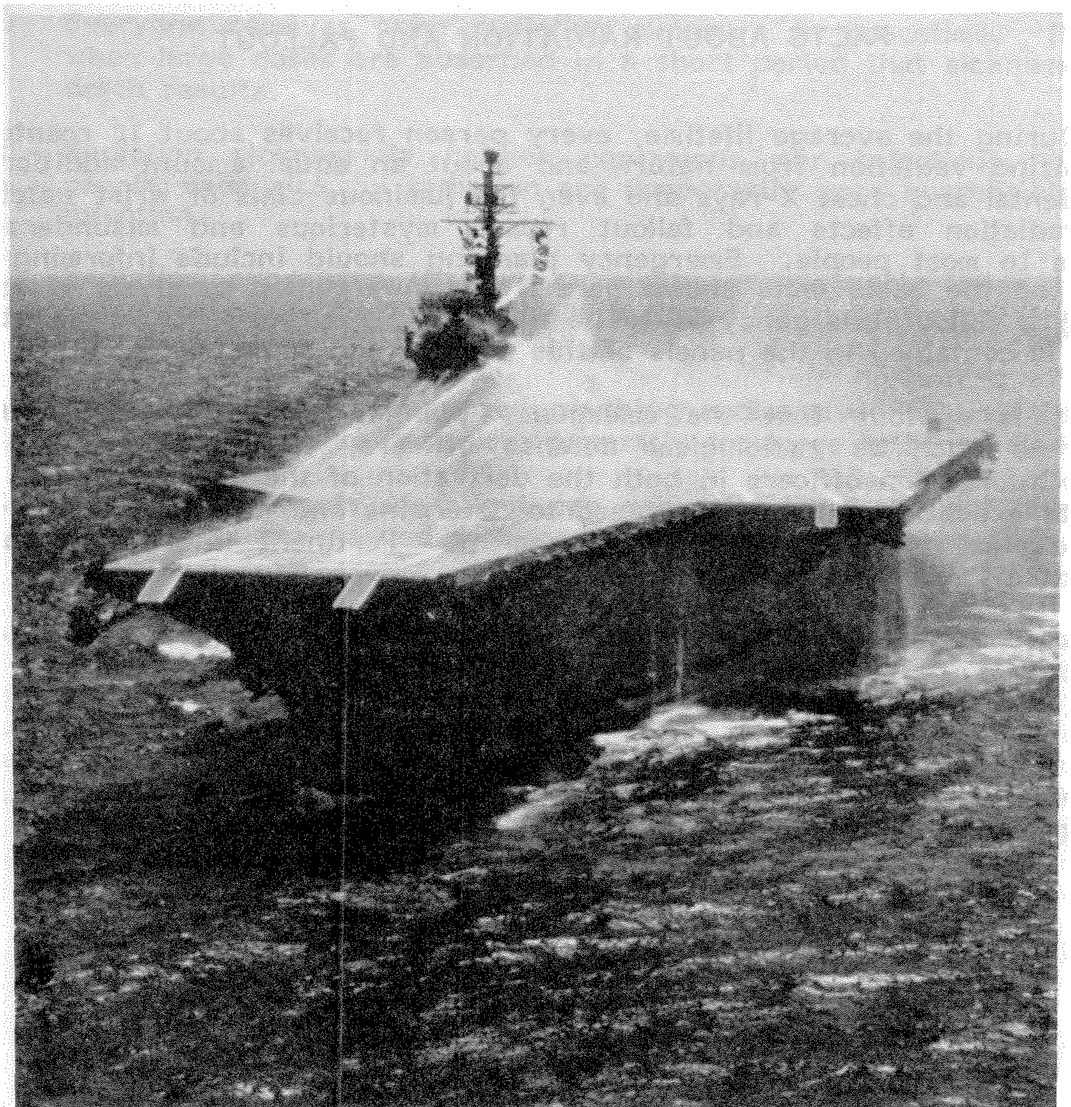


WHAT ABOUT BOATS?

The fact that a large part of the radiation from fallout comes from contaminated areas a considerable distance away has suggested that boats and ships located on bodies of water (lakes, rivers, and bays) might provide good fallout protection. Fallout particles will settle rather quickly to the bottom. Three to five feet of water will provide ample shielding from this fallout. Thus, if a boat is anchored or lying at least several hundred feet offshore, nearly all of the radiation exposure will come from fallout actually deposited on the boat. Most fishing and pleasure boats are quite small, and the fallout protection factor from being on the water would be about 4 or 5, better than aboveground floors in a house but not as good as most basements.

The protection can be greatly improved by rigging a tarpaulin or awning over cockpit areas and shaking or sluicing the canvas to dislodge the fallout particles when visible deposits appear. Exposed decks can also be sluiced by hose or bucket. Thus, a combination of lying offshore and early decontamination can generally result in an equivalent fallout protection factor of 20 to 40. If no better fallout protection is available, boats may be considered in localities where they are plentiful.

Ships may also be useful in many circumstances. They can carry large numbers of people. Because they are larger than boats, the radiation levels from fallout deposited on the decks more nearly approaches the level that would occur on shore. The steel construction will offer significant shielding, but prompt decontamination is also necessary to achieve a reasonable amount of fallout protection. The topside areas of ships are readily flushed off. Most navel ships and some merchant ships have washdown equipment to accomplish rapid decontamination. A washdown system in action is shown here.



PHOTOGRAPH OF USS KITTY HAWK UNDER WASHDOWN
(Courtesy of Office of Chief of Naval Operations)

FACTS ABOUT RADIATION AND FALLOUT

During the average lifetime, every person receives about 10 roentgens of ionizing radiation from nature and about an equal amount additionally from dental and chest X-rays and even the luminous dials of wrist watches. Yet radiation effects and fallout remain mysterious and misunderstood threats to most people. Emergency planning should include informing the public on the basic facts shown here if an unwarranted paralysis of action during a fallout emergency is to be avoided. The basis for these statements is contained in the panels of this chapter and those of chapter 5.

It is obvious that the emergency planner should use appropriate resources such as radiological defense officers, health physicists, and public information officers in both the derivation of the operations plan but also its execution. There is a need to determine and document to the best of one's ability the radiation environment. Pertinent information should then be disseminated to the public.

SOME BASIC FACTS

1. Everyone receives some radiation exposure in peacetime. It is when large doses are absorbed in a short period that sickness or death results.

2. Radiation sickness is neither contagious nor infectious. But people made sick by radiation are temporarily more susceptible to infection.

3. Radiation exposures that cause sickness are much lower than those that cause death. Being sick does NOT indicate that one is necessarily going to die.

4. Fallout radiation cannot make anything radioactive. Fallout itself consists of sandlike particles, generally too large to be inhaled.

5. Dangerous amounts of fallout can generally be seen, but special instruments are needed to measure the danger of radiation exposure.

6. Radiation exposure can be kept below sickness levels by using good fallout shelter; by delaying outside activities until radioactive decay has reduced the exposure rate; and by limiting the time of exposure on urgent tasks.

7. No one should thirst or starve for fear of contaminated water or food. Illness can be caused as readily by malnutrition, dehydration, and poor sanitation as by radiation injury.

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