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RADIATIONS FROM FALLOUT AND THEIR EFFECTS

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FORMATION OF RADIOACTIVE PARTICLES

At the time of detonation of a nuclear weapon, about 60 different isotopes are formed, representing some 35 elements. Most of these give rise to decay chains consisting of several isotopes so that there may be 170 isotopes produced eventually.

In terms of activity, a one megaton detonation (1,000,000 tons) TNT equivalent energy produced by fission of atoms will result in about 300,000 megacuries of radioactivity, measured one hour after the burst. In addition there may be present induced radioactive isotopes resulting from the reaction of neutrons released at the time of detonation, with natural materials such as soil and water. /A fusion reaction produces no radioactive substances directly but may cause induced activity because of its release of neutrons./ The total radioactivity of the products of a fission reaction will greatly exceed that of the activity induced in the soil or water. In the case where the fireball clears the ground, there will be a relatively small percentage of the total fission product activity deposited around ground zero and the neutron induced activity probably will be much greater. However, none of the neutron-induced isotopes that might be produced in appreciable quantities have long half-lives.

Shortly after a nuclear burst, some of the radioisotopes combine with oxygen to form negative radicals while the halogens form halides which combine with the strongly electropositive elements to form compounds. The noble gases such as radiokrypton and radioxeon remain in the atomic state until they decay to a daughter isotope which can form an oxide or halide. With the rapid cooling of the fireball, there is condensation of the isotopes and inert materials.

In the case of an air burst there will be available only small quantities of relatively fine particles of dust in the air and debris from the bomb casing to act as a transport vehicle for the radioisotopes. When the fireball intersects the ground the intense heat melts or vaporizes large quantities of soil and transports them aloft to act as carriers for the condensing radioisotopes. A characteristic toroidal motion sweeps this debris in and around the fireball where the melting temperature is reached and the particles come in contact with the fission products still in gaseous form. Subsequent cooling results in the radioactive isotopes becoming associated within and on the surface of the particles. It has been estimated that from 50 to 90 percent of these particles are between 50 and 1,000 microns in diameter. Of these, probably less than half of the larger particles falling out near the site of the detonation will possess any activity, since most particles will not reach sufficiently high temperatures to incorporate the radioactive materials, and dry, relatively cool, soil is a poor scavenger.

The high yield weapon detonated at the Pacific Proving Ground in the fall of 1952 resulted in a crater in the coral nearly a mile in diameter and 175 feet deep. Although a minor factor in the crater production might have been the compression of the coral by the blast, probably more than a hundred million tons of material were dislodged and thrown into the air. The exact results might not be reproduced for a detonation over continental land areas or built-up cities but in general the effects would be similar.

DISTRIBUTION OF RADIOACTIVE PARTICLES

For nominal bombs (in the range of 20 kiloton yield) the atomic cloud will not rise above the tropopause. (The tropopause marks the level below which is the turbulent air flow of the troposphere and above which is the relatively stable nonturbulent air of the stratosphere). The cloud from a high yield weapon will penetrate into the stratosphere as illustrated by the photograph on page ____ of the detonation during Operation Ivy in the fall of 1952. Two minutes after the explosion the cloud had risen to 40,000 feet and ten minutes later neared its maximum height of over 100,000 feet. The smaller particles carried into the stratosphere will settle only very slowly until they reach the troposphere where the turbulent air and rainfall will carry them much more rapidly to the earth's surface.

The stratospheric storage is uniquely significant since the mixture of radioisotopes present there is enriched in strontium-90, the element of most concern for long-term hazards. This is because strontium-90 has a gaseous precursor krypton-90 with a half-life of 25 seconds. Thus, at the time when conditions are optimum in the fireball for the oxides and halides to become associated with molten inert particles, only a fraction of strontium-90 has formed and the gaseous krypton parent is largely carried into the stratosphere. This results in the nearby fallout (within several hundred miles downwind) being partially depleted in strontium-90 while that at more distant areas will be enriched.

The activity placed in the stratosphere circles and recircles the earth, first at the same general latitude as the burst and then slowly spreading laterally. At the same time there will be a slow diffusion into the tropopause. Initially, there will be more deposition in the same hemisphere (northern or southern) in which the burst occurred but after many months the rate of deposition may become more generally uniform over the entire earth's surface. In terms of strontium-90 about 10 to 20 percent of the activity remaining in the stratosphere may descend each year.

The distribution of the nearby fallout (up to several hundred miles downwind) from high yield weapons detonated near the earth's surface will be determined principally by particle size, initial position in the steam and cloud, and by the wind structure at various altitudes. The particle sizes and the distribution of these particles within the stem and cloud are principally functions of the yield of the bomb, the nature of the surface over which the burst occurs and the quantity of material vaporized. There are uncertainties in our knowledge but Figure 1 presents one generalized concept of such an initial distribution. Although the cloud may be 100 miles in diameter, the activity probably is not uniformly distributed, but rather is more concentrated near the central and lower portions of the cloud.

The influence of the wind structure at various altitudes on the ground distribution of the nearby fallout is qualitatively represented in Figure 2. The last sketch in Figure 2 illustrates the effects of the "shearing" action of the winds when they travel in different directions and/or speeds at the various altitudes through which the particles must fall. Due to these wind conditions, it is possible to obtain fallout patterns ranging from one looking like an ink blot around ground zero at one extreme, to other situations where the fallout material is spread in a long thin finger. In general, the pattern may be expected to approximate an ellipse.

It is clear that such variables as wind conditions and the yields of nuclear bombs and their positions of detonations above different types of surface make it impossible to predict fallout patterns precisely. In the case of nuclear weapons testing these variables are either known or can be predicted with good accuracy. However, in civil defense planning, certain assumptions concerning these variables must be used in estimating not only a single fallout pattern, but also possible overlapping patterns in the event of multiple detonations.

RADIATIONS AND FALLOUT

In describing and evaluating the effects of fallout patterns, it is necessary to consider the characteristics of the radiations emitted from the radioactive material. These are of three types: gamma rays, beta particles and alpha particles. Gamma rays are the emissions of principal concern, because of their greater penetrating power. The most energetic beta particles travel only a few yards in air and are of concern only when the fallout materials remain in contact with or in very close proximity to the skin, or when the emitting materials find their way into the body. The amount of alpha emitting isotopes associated with fallout material is considered to be of relatively minor consequence.

EXTERNAL GAMMA EXPOSURE

The gamma radiation dose that one may actually receive and the biological effects are dependent upon a number of factors, as follows:

1. Radiological decay.

The decrease in radioactivity of fallout material roughly follows the relationship of $(\text{time})^{-1.2}$. This means that, for every sevenfold lapse of time after a nuclear explosion, there will be a tenfold reduction in dose rate. For example, if fallout occurs one hour after a detonation, such as might occur for twenty or thirty miles around ground zero of a high yield weapon, the dose rate will be one-tenth of its initial value by the seventh hour. An additional tenfold reduction would require seven times seven hours or approximately two additional days of waiting. The theoretical* dose accumulated from the first to seventh hour after detonation would be approximately the

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* Calculations of theoretical doses are based on (a) the radioactivity decreasing according to $(\text{time})^{-1.2}$, (b) there is no loss of activity by weathering effects, and (c) the person is out-of-doors for the time considered.

same as that from the seventh hour until one week later. Further, this first-week dose would be about twice as great as the entire remaining dose possible for the lifetime of the activity. (Figure 3). This rapid decay suggests the benefits of protection in the early periods after fallout and, where possible, delay of entry into a contaminated area.

In localities downwind where initial fallout might not occur until say, 24 hours after a detonation, the situation would be somewhat different, in that the radioactive decay would be slower. For example, consider the cases where fallout occurred at (a) one hour, and (b) 24 hours, after a detonation. One day after fallout the dose rate in the first case would be 1/45 of its initial activity (1st hour), but in the second case the dose rate would have decreased to only slightly less than 1/2 of its initial activity (24th hour).

The above estimates are based on an assumed radiological decay of $(\text{time})^{-1.2}$. This is reasonably accurate for early periods of time after detonation, but the decay may start to vary significantly from the theoretical curve after several months have elapsed. (Figure 4). At times later than shown in Figure 4 the decay curve would be expected to flatten out due to the presence of long lived cesium-137. (Twenty-seven year half-life)

2. <u>Weathering and shielding effects</u>.

The magnitude and time of occurrence of weathering and shielding makes it impossible to establish a single establishment of a precise rule of effects covering all situations, impossible, yet these factors are operative in determining the total exposure received from fallout.

One example of weathering effects was after the March 1, 1954 fallout on the Marshall Islands in the Pacific. Figure 4 shows the gamma dose rates on the Island of Rongelap over a period of about two years. In the first ten days when the winds were light and there was no rainfall, the decrease in activity was roughly consistent with known radiological decay rate. The break between the tenth and twenty-fifth day undoubtedly represents the effects of rain which was known to have occurred in that period. Figure 4 suggests, however, that any further reduction in contamination by rainfall was slight.

An example of the effects of winds, occurred after one of the nuclear detonations at the Nevada Test Site in 1953. Strong winds blew almost at right angles across a narrow band fallout field on the 2nd and 3rd day after the detonation. The gamma dose rates at three feet above the ground on the 4th day were less than predicted by the relationship of $(\text{time})^{-1.2}$ by factors ranging from three to six, while the activity of the soil samples collected on the first day and taken into the laboratory did decrease approximately as $(\text{time})^{-1.2}$. This effect of winds would not be expected to be as great for large contaminated areas of non-sandy soils.

Calculations of shielding and attenuation factors for different types of materials and theoretical calculations for various structures are plentiful references through 11 (Table 1), but more information based on actual field experience is needed. Limited data were obtained during Operation Teapot (Spring 1955) where film badges were placed inside and outside of buildings for several days. The ratio of out-of-doors to indoors doses ranged from 1.3 to 7 with one room frame buildings providing the least attenuation factor and multiroom concrete block buildings the greater values. This program will be expanded during Operation Plumbbob as will the program of estimating personnel exposure by having a large number of people living around the Nevada Test Site wear film badges during and following the test series.

3. Gamma energy spectra.

The relative biological effectiveness of differing energy photons and their varying depth-dose curves has been shown for X-rays.[12] Similar results have been obtained for gamma rays as illustrated by one set of experiments[13] using burros where there was a shift of LD 50/30 values (lethal dose to 50% of the exposed animals who died in 30 days) from 684 roentgens with cobalt-60 (1.25 Mev mean energy) to 585 roentgens with Zr^{95} - NB^{95} ($\sim$0.7 Mev mean energy). The gamma energy spectra from the mixture of isotopes in fallout is quite complex and is further complicated by the presence of scattered radiation, with its lesser energies, mixed with the direct radiation. Figure 5 illustrates the estimated gamma spectra at three feet above the ground following the detonation of March 1, 1954 at the Pacific Proving Ground.[14]

4. Geometry of the source.

The geometry of the source can make a significant difference in depth-dose curves and resultant biological effects. This may be illustrated by one experiment using swine where the LD 50/30 values for external dose decreased from 500 to 350-400 roentgens when the exposure was changed from unilateral to bilateral (the radiation exposure was first on one side only, then from opposite sides of the subject).[12] With a fallout field, the source probably would be more radial, thus a "roentgen" as measured in air would have more biological effect than one where the source is unilateral such as from the immediate radiations at the instant of a burst (although there is some scattered radiation), or from X-ray machines which have been used frequently with unilateral beams in developing data on biological effects of radiation.

5. Biological repair factor.

It has been recognized that, in general, the longer the period over which a given radiation dose is delivered, the less is the resultant biological effect, except for such aspects as the genetic effects and life shortening. In situations of heavy fallout and relatively large potential radiation doses, the biological repair factor may be considered in estimating incapacitating and lethal doses. Since past experiments usually have been designed for other purposes, the data from these do not readily elucidate the rate of repair or the proportions of reparable and irreparable damage resulting from differently timed doses. Varying relationships have been demonstrated, depending upon the species or even the strain of animal, as well as the criteria selected for study, such as skin damage, life shortening, and LD 50 values. Our present knowledge does not permit establishment of a precise overall relationship for timed doses versus biological effects; yet there are sufficient convincing data to permit an attempt at estimating the effect of this phenomenon.

Blair, Smith, Sacher, Davidson[15, 16, 17, 18, 19] and others have made extensive analyses of existing data on the effects of time-spaced doses for several species of animals. Generally, the recovery rate for larger and longer-lived mammals, such as dogs, is significantly less than for mice. One estimate places the half-time recovery for man as long as four weeks (the time for one-half of the biological damage to be repaired).[19]

Since the estimated rate of biological recovery for man is relatively slow, this factor would have its greatest influence where a given total radiation dose was delivered over long periods of time. This would be the case where the fallout occurred at later times after detonation rather than close-in areas where the fallout is essentially complete in about an hour after the burst, and about one-half of the total possible dose is delivered in the first 24 hours.

NEARBY FALLOUT FROM HIGH YIELD WEAPONS

As an exercise during the National Association of Civil Defense Directors meeting in Washington, D. C. on April 15-17, 1957, it was assumed the 4 bombs were dropped simultaneously as follows: 20 megaton on the Union Station Washington, D. C., 5 megaton on the National Airport, 20 megaton on Baltimore, Maryland and 10 megaton on the Patuxent River Naval Air Station. The map on page ____ shows the combined fallout from these 4 bombs. The isodose rate lines are in units of roentgens per hour at one hour after detonation. By this time essentially all of the fallout would have occurred in these nearby areas.

Recalling that the radioactive decay is rapid for this fallout that occurs early after detonation, it becomes evident that if adequate protective areas are available it would be wiser for people to remain in place, rather than be exposed out-of-doors during the period of highest activity. Likewise, if a delay in movement is possible there will be more of an opportunity to evaluate the situation, and to then affect an orderly evacuation.

Since each situation will be unique, no rigid criteria will be proposed here for permissible exposures or for mandatory evacuation, since there may be other factors present as potentially hazardous as radiation. Rather, Table 2 was developed to illustrate the kind of thinking and planning possible for civil defense. Three levels of exposure to civil defense workers are shown. The lowest of 25 roentgens is much higher than is permitted in peacetime, yet most personnel will retain their full working capacity even with exposures up to 100 roentgens.

Table 2 suggests several points relative to rescue. One of these, is that higher permitted radiation exposures to rescue crews would allow earlier entry into the contaminated area to affect first aid and general rescue work. Also, in the case of relatively little protection to the populace, there would be a saving in radiation exposure to them. On the other hand, people better sheltered, as illustrated in Column V, would receive less total exposure if they stayed in the protected areas until the out-of-doors activity had decreased, and at the same time a delay of entry into the contaminated area would result in less radiation exposure to the rescue crews who might then be used again for other missions.

DISTANT FALLOUT PATTERNS FROM HIGH YIELD WEAPONS

The discussion above suggests the wide variability possible in distant fallout patterns from high yield weapons and the great variation in radiation dose that one may receive due to shielding and weathering effects. Therefore, the following analysis is intended to be only a generalized one to illustrate the parameters and how they may operate in determining the radiation doses.

Consider the case of fallout from a high yield weapon where people continue to live in an area without any special measures to protect themselves. Assume (a) for the first week following the fallout, the measured gamma activity decays according to $(\text{time})^{-1.2}$, for the second week $(\text{time})^{-1.3}$ and for the third week and thereafter $(\text{time})^{-1.4}$, and (b) the shielding factor afforded by normal housing will reduce the out-of-doors daily dose by 25%, and (c) the half-time of repair of biological injury is four weeks. Probably all of these assumptions are conservative, i.e., they overestimate the hazard. Based on these assumptions, Figure 6, shows the dose rates at time of fallout or entry into an area that might produce an "effective biological dose" (the term given to the radiation exposure according to the above assumptions) of one roentgen.[20] This graph may be extrapolated to other readings. For example, if fallout begins three hours after detonation and the dose rate at that time is 10 r per hour, about 67 r (effective biological dose) will be accumulated provided personnel continues to live normally in the contaminated area. This is computed as follows:

$$\frac{10}{0.15} = 67$$

It is frankly recognized that in any single curve, such as that shown in Figure 6, there are inherent a number of uncertainties. Criteria based on deliberate analyses of the relevant data, however, may be more valid than those determined under the duress of an emergency situation. Such a simplified graph might provide radiological monitors with a quick, even if rough, estimate of the potential hazards and thus assist in making decisions on questions such as evacuation.

Using Figure 6, the idealized fallout diagram on page ____ was constructed to illustrate a possible pattern from a single high yield surface burst.[20]

The two innermost isodose lines shown were selected to suggest regions where (a) a significant percentage of personnel might be expected to die (400 r) and (b) a few percent to become ill (100 r), assuming continued occupancy of these areas with no special protective measures. These percentages would, of course, rise within the encompassed areas. The 50 r effective biological isodose line has no unique significance but suggests the magnitude of dose which might call for emergency measures against radiation exposures even in the face of other possible hazards. Table 3 shows the approximate areas encompassed by the three isodose lines. For areas where the fallout occurs a few hours or more following detonation, many days or weeks will be required to accumulate the major portion of effective biological doses, so that spot decisions involving additional hazards might not be necessary.

The question is frequently asked as to the time one must spend within a shelter or remain outside of a contaminated area. The answer depends upon a number of parameters, such as the criteria established for maximum permissible dose, as well as length of stay within the area of contamination. With knowledge of the magnitude of the radiation levels present and an assumed rate of decay, $(t)^{-1.2}$, it is possible to plan and execute a short stay even in a highly contaminated area. Planning for continuous occupancy requires more extensive analysis. The following data may aid in such evaluation.

The fallout map (Idealized Fallout Diagram on page ____) and Table 3 suggest the degree of radiation exposure received in continuous occupancy under normal living conditions beginning with the time of initial fallout. For those entering the contaminated zone four months after the first fallout, however, and then living there indefinitely, the area encompassed by the 50 r effective biological isodose line will have shrunk from about 25,000 to 2,500 square miles. At such time (four months after fallout), an area of about 1,000 square miles within the 50 r isodose line might have the highest residual contamination, amounting to about three times the dose rates at the periphery.

The 0.3 r per week out-of-doors isodose-rate line might extend to about the same position as the line marked 50 on the map.

As one attempts to extrapolate such data to one year after fallout, the analysis becomes still more difficult and uncertain. The data suggest, however, that if return is postponed to one year after fallout, the 50 r effective biological isodose line will have disappeared. On the basis of these conservative estimates, the 1,000 square miles of highest contamination might have an out-of-doors dose rate of about 4 r per week after one year. Similarly, personnel might accumulate a dose of about 100 r for the first year following their return, and an additional 90 r over the next three years, independent of the biological recovery factor. It is to be expected that this factor would be relatively great for such long periods of time, thus reducing the effective biological dose below 50 r. The 0.3 r per week out-of-doors isodose-rate line might encompass an area somewhat larger than the line marked 400 on the map.[20]

For such effects as genetic, it is the total dose received that is important since biological repair does not enter in such calculations. According to the conservative estimates of weathering and shielding used above, possibly several hundred roentgens might be delivered in the areas of heaviest contamination, from the end of the first year after the fallout occurred until the radioactivity had decreased to essentially zero. However, the foregoing analyses are based on passive factors only, not taking into account the actions of persons themselves in reducing contamination. If, for example, a permanent return into an area were postponed for one year after fallout, the radiological situation probably would have been adequately appraised, and decontamination operations initiated. (This subject will be discussed by others.) Moreover, with the return of a populace into a known contaminated area, more than normal precautions might be expected in regard to occupancy of the more protective types of buildings and reduction of time spent out-of-doors.

Of course, greater degrees of contamination could result from multiple overlapping fallout patterns. There is a need for continuing studies of these problems.

ENVIRONMENTAL CONTAMINATION

Radioactive contamination of an area will, of course, influence agricultural pursuits. An evaluation of these problems involves complex and difficult studies which will not be attempted here. In terms of civil defense, however, there is one phase that should be noted here.

The relatively heavy fallout that occurred on some of the Marshall Islands in March 1954 provides the most direct data. Since the time of this fallout there have been 10 radiological and biological surveys of these islands. All of these data are summarized in a report prepared by the Atomic Energy Commission and in press with the Government Printing Office.[21]

There are strikingly wide variances in the degree of gross contamination in the soils and in the plant and animal life. Likewise, relatively large ranges in values were found for the individual isotopes in the plants and animals. Any conclusions, therefore, must be of only the most tentative and generalized nature.

The data do suggest that in terms of strontium-90, the isotope of principal concern, this activity built up in the plant life over the first year after fallout and then started decreasing slowly. By using very rough approximation, and extrapolations, the data suggest that if plant life had been growing in the area of highest contamination it might have contained 10-30 microcuries of strontium-90 per kilogram of calcium, at one year. The corresponding values for the soils are several times higher. If an assumption is made that there is a discriminatory factor of about four for the Sr/Ca ratio in plants versus bones, the above data suggest possible levels of strontium-90 in the bones of animals from continuous consumption of this food of a few to several microcuries of strontium-90 per kilogram of calcium. The maximum permissible body burden for adult atomic energy workers is one microcurie of strontium-90 per kilogram of calcium.

There is some confirmatory evidence for this crude evaluation. A variety of native animals were left on the Island of Rongelap after the fallout in March 1954. They have been collected and sacrificed serially in time. Even after two years of continuous occupancy it was reported that there were no pathological changes that could be ascribed to radiation.[22] Their bones showed from about a one-tenth to a few tenths of a microcurie of strontium-90 per kilogram of calcium. Since the areas of highest contamination were about 12-14 times greater than Rongelap, an extrapolation would suggest values in the same range as above, i.e., a few to several microcuries of strontium-90 per kilogram of calcium if animals had lived in the area of greatest contamination.

The pacific island soils have higher calcium content than most soils in the United States, and of course there are differences in the type of plant life and in the climate. However, theoretical calculations suggest that the same fallout in the United States might result in something like 100 microcuries of strontium-90 per kilogram of calcium in the soils with the highest contamination. With assumed discriminatory factors from soil to bones of 10 or more, the implied eventual body burden of strontium-90 is of the same magnitude in the Pacific.

The uncertainty of these data, however, would not deny the possibility that for a similar fallout in the United States there might eventually result a body burden of 10 or more microcuries per kilogram, if people were to subsist entirely on food from the area of highest contamination. With <u>maintained</u> values two to three times this amount, it might be expected that a few percent might die of bone tumors after a latent period of 15 to 20 years. It would be expected, however, that the strontium-90 content in the food supply would slowly decrease with time. Any measures taken to reduce the uptake of strontium-90 into the food supply, and any supplemental foods from less contaminated areas would lower the strontium intake.

For civil defense purposes, a full evaluation of the whole environmental contamination problem is needed, especially for the cases of multiple overlapping fallout patterns from many nuclear detonations which might occur under wartime conditions.

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EXTERNAL BETA EXPOSURE

The second principal emission from the fallout material is beta particles. These are essentially high speed electrons, of which even the most energetic travel only a short distance into the skin. (See the next section for discussion on Internal Exposures.) If large enough radiation doses are delivered by these beta particles, the skin may first show erythema (reddening) and then proceed to more serious damage. If a sizeable fraction of the body should suffer serious skin damage from these beta radiations, the results would be similar to those from thermal burns, i.e., serious injury or death.

There is little doubt that "beta burns" can and have occurred. In the case of the Marshallese who were in the fallout from the detonation at the Pacific on March 1, 1954, most of the more heavily exposed showed some degree of skin damage, as well as about half of them showing some degree of epilation due to beta doses.[22] However, none of these effects were present except in those areas when the radiation material was in contact with the skin, i.e. the scalp, neck, bend of the elbow, between and topside of the toes. No skin damage was observed where there was a covering of even a single layer of cotton clothing. In fact, the beta radiations eminating from the radioactive material on the ground should have been adequate to produce detectable skin damage (based on the amount of contamination present) yet this was not observed.

These findings indicate the obvious benefits to be expected from (a) remaining inside during the time of actual fallout to reduce the possibility of direct body contamination, or if out-of-doors, to keep the body covered and, (b) early removal of the body contamination since higher doses are delivered during early times after fallout.

The Marshallese were semiclothed, had moist skin, and most of them were out-of-doors during the time of fallout. Some bathed during the two-day exposure period before evacuation, but others did not, therefore, there were optimal conditions in general for possible beta damage. The group suffering greatest exposure showed 20% (13 individuals) with deep lesions, 70% (45 individuals) superficial lesions and 10% (6 individuals) no lesions. Likewise, 55% (35 individuals) showed some degree of epilation followed by a regrowth of the hair. However, during this same period of time they received a whole-body gamma dose of 175-roentgens — a value approaching lethality for some of those exposed. These data, together with others, indicate that the external gamma radiation would be the controlling factor for making such decisions as to evacuation, although recognizing that any beta exposure would be an additional body insult.

INTERNAL EXPOSURES

The principal factor in evaluating long term hazards from ingestion and inhalation is the doses delivered to the bones by isotopes of strontium. This subject will be discussed in detail by others.

The principal hazards from intake of relatively large amounts of radioactive fallout for several weeks immediately following a nuclear detonation are doses to the:

a. gastrointestinal tract, from the gross fission product activity,

b. thyroid, from isotopes of iodine, and

c. bone, principally from isotopes of strontium and barium-lanthanum.

The solubility of the fallout material is a major factor in determining the resultant fate, and thus radiation doses, within the body. The solubility varies, depending among other factors upon the surface over which the detonation occurred. The fallout material collected in soil samples at the Nevada Test Site has been quite insoluble, i.e., only a few percent in distilled water and roughly 20-30 percent in 0.1 N HCI. However, it would be expected that the activity actually present in drinking water supplies would be principally in soluble form. The water collected from a well and a cistern on the Island of Rongelap about 21 months after the March 1, 1954 fallout, was found to have about 80 percent of the activity in the filtrate, but there was an undetermined amount that settled to the bottom. Other data suggest the material to have been about 10-20 percent soluble in water.

Figure 7 shows <u>relative</u> doses to the body organs, based on the assumptions that (a) 90% of the material is insoluble (when calculating doses to the gastrointestinal tract), (b) all of the isotopes of iodine are soluble (when estimating doses to the thyroid), and (c) 25% of the ingested strontium isotopes and 7% of the barium-lanthanum reached the bones. It may be seen that ingestion of a given amount of fission product activity on the fourth and fifth days may result in nearly two and one-half times the dose to the thyroid as to the lower large intestine. For a continuous consumption of fallout material from the first hour to the 30th day the ratio of doses is about 1.7. Table Four indicates the amount of ingested fission product activity to produce one rad dose to the lower large intestine.

Analyses of past data strongly indicate the quantity of fallout material taken in for times immediately following a detonation: (a) by inhalation is very much less than by ingestion (unless of course one does not eat or drink), and (b) may come from surface contamination of the food rather than by the soil-plant-animal cycle.

How much intake is actually permitted depends upon many factors including the essentialness of the food and water to sustain life, and one's philosophy of acceptable biological risks and damages in the face of other possible hazards such as mass evacuation. By using Table 4 and Figure 7, an estimate may be made of the radiation doses that might result from the ingestion of a given amount of fission product activity. In determining how much actual ingestion, and thus the radiation doses that might be permitted, reference may be made to Table 5 which suggests the biological effects from certain doses.

Such evaluations as attempted here are necessary and valuable for planning purposes, but once the fallout occurs the emergency of the situation may preclude immediate analysis of the food and water supplies. Further, the abstinence from food and water because it might be contaminated could not be continued indefinitely. Therefore, the following three common-sense rules are suggested:

1. Reduce the use of contaminated food and water to bare minimum until adequate monitoring can be

performed; use first any stored clear water and canned or covered foods; wash and scrub any exposed foods.

2. If the effects of lack of food and water become acute, then use whatever is available but in as limited quantities as possible. Whenever possible select what seems to be the least likely contaminated water and/or foodstuffs.

3. Since it is especially desirable to restrict the intake of radioactivity in children, give them first preference for food and water having the lowest degree of contamination.

In an area of heavy fallout one matter to consider is the relative hazards from the external gamma exposure versus internal doses from ingestion of the material. One of the best evidences on this point was the fallout that occurred on the Rongelapese in March 1954. Those in the highest exposure group received 175 roentgens whole body external gamma exposure yet their body burdens of internal emitters were relatively low.[22] These and other data suggest that:

If the degree of contamination of an area for several weeks immediately following a nuclear detonation is such that the external gamma exposure would permit normal and continuous occupancy, the internal hazard would not deny it.

This is based on such reasonable assumptions of (a) about 50% reduction of gamma exposure from out-of-doors doses afforded by living a part of each day in normal family dwellings, (b) washing and/or scrubbing contaminated foods, and (c) excluding areas where relatively little fallout occurred, but into which may be transported highly contaminated food and/or water. After longer periods of time during which the gamma dose rates in an originally highly contaminated area have decreased to acceptable levels, it probably would be necessary to evaluate the residual contamination for the bone seeking radioisotopes, especially strontium-90.

NUCLEAR WEAPONS TESTING

Since 1951, the United States has conducted 11 series of nuclear tests, five at the Nevada Test Site and six at the Eniwetok Proving Ground, for a total of more than ~~57~~ 63 test detonations. A sixth series is currently underway at the Nevada Test Site. The fallout on the inhabitants of some of the Marshall Islands in March 1954 (which will be discussed by others) and fallout on some Japanese fishermen, have been the major effects off the testing areas. The only other off-site damage has been in the United States where the blast wave has caused minor structural damage for which about $45,000 has been paid in claims,[23] and fallout that occurred on some horses and cattle grazing within 20 miles of ground zero causing skin burns for which about $15,000 was paid.

At the Eniwetok Proving Ground, where the larger devices are tested, the warning area covers nearly 400,000 square miles. This area is under constant surveillance during the time of testing both by surface ships and by aircraft. Starting two days prior to a detonation, the search is intensified in the sector of probable fallout. If any transient ship is located in the warning area, it is advised to leave and the detonation is delayed until it is clear.

Fully manned weather and fallout prediction units are an integral part of the Task Force conducting the tests. Since the larger detonations in the Pacific require additional information on the upper air, new types of high altitude balloons and missiles are used. Nine weather stations are established by the Task Force during the test series on islands around the Site, in addition to the eight regular weather stations in operation on other islands.

After each detonation, aircraft track the radioactive air out for several hundred miles. Other aircraft, with special monitoring equipment fly over land and sea areas to measure any residual contamination.

Through the cooperation of the U. S. Public Health Service, trained monitors were present during Operation Redwing (Spring 1956 series) on the populated Islands of Wotho, Ujelang and Utirik.

As would be expected, the delineation of fallout patterns in the wide expanses of the Pacific is difficult. For the immediate monitoring, aerial surveys are conducted as mentioned above, automatic equipment are placed on land areas, and a variety of ships, skiffs, and buoys are utilized. Following each test series, large scale radiological and biological surveys are made. Data from these surveys have been summarized by the Commission in a document soon to be published by the Government Printing Office.[21]

The Nevada Test Site covers an area of about 600 square miles, with the adjacent 4,000 square miles being a U. S. Air Force Gunnery range.[24] Surrounding these areas are wide expanses of sparsely populated land. For general safety, as well as security, the Nevada Test Site is closed to the public. Aerial and surface surveys are made to insure that no persons or animals wander into the area. Each nuclear detonation is publicly announced ahead of time.

As a part of the Test Organization there is an advisory panel of experts in the fields of biology and medicine, blast, fallout prediction and meteorology. A series of meetings is held before the firing of each shot to weigh carefully all factors related to the safety of the public.

A complete weather unit is in operation at the Nevada Test Site, drawing upon all of the extensive data available from the U. S. Weather Bureau and the Air Weather Service, plus six additional weather stations ringing the test site. These data are evaluated for the current and predicted trends up to one hour before shot time. A shot can be cancelled at any time up to a few seconds before the scheduled detonation. In the past, more than 80 postponements have been made due to unfavorable weather conditions.

Several measures have been used to reduce the radioactive fallout off the test site. First, of course, only small nuclear devices are tested at Nevada. Since the greater the height of the fireball above the surface the less is the fallout in nearby areas, the test towers have been extended to 500 feet, and during Operation Plumbbob (Spring 1957) there will be at least one 700-foot tower. Also, a new technique of using captive balloons is being developed. Extensive tests are being conducted to determine the feasibility of detonating nuclear devices so far underground that all of the radioactive material will remain captured and thus, of course, completely eliminate any fallout.

Prior to each nuclear detonation a "warning circle" is established for aircraft, designed to provide control of aerial flights within the area of predicted path of the atomic cloud. A representative of the Civil Aeronautics Administration is assigned to the test organization and assists in establishing the controlled area. This may typically extend about 150 miles in radius and be in force for a period from about H minus one-half hour to H plus 10 hours. All aircraft are required to check through the Civil Aeronautics Administration before flying in this area.

After each nuclear burst, aircraft from the Test Organization track the cloud until it is no longer readily detectable. Behind this come other aircraft to plot the fallout pattern on the ground. This survey is repeated on D plus one day.

The off-site monitoring program during Operation Plumbbob (Spring 1957) illustrates the extensive system organized not only to take numerous radiological measurements but also to provide close liaison with the citizens of nearby communities. The Atomic Energy Commission and the U. S. Public Health Service jointly organized a program wherein the areas around the test site are mapped out into 17 zones. A technically qualified man has been assigned to live in each zone. His duties consist not only of normal monitoring activities but also, prior to and during the test series, of learning the communities and families in his zone, getting to know the people and having them know him. In addition to the 17 zone commanders, as they are called, there are eight mobile monitoring teams on call to go to any locality to assist if needed or to travel to areas outside the 17 zones.

Four additional monitoring programs are also in operation. One of these projects is primarily of research nature yet provides radiation monitoring data out to 160 miles or more from the test site. A second program is a unique system of telemetering, whereby instruments are placed in about 30 communities around the test site and connected to commercial telephone wires. The operator sits at the control point and, by placing a normal telephone call, receives back signals that are translated in a matter of seconds into gamma radiation dose rates. A third project consists of automatic instruments located in another 15 communities that permanently record the gamma dose rates continuously from the beginning to the end of the test series. A fourth program consists of aerial surveys with special gamma detection instruments.

Extending outward from the Test Site across the country are 38 U. S. Public Health Service monitoring stations established in cooperation with the Atomic Energy Commission, and 11 AEC installations (See Tables 6 and 7). In addition, through the cooperation of the U. S. Weather Bureau 93 stations in the United States make gummed paper collections of fallout (Table 7). These gummed paper collections are also made world-wide at 73 other locations by arrangement with the Department of State, U. S. Weather Bureau, U. S. Air Force and Navy (Table 9).

RADIATION EXPOSURES TO THE PUBLIC

The data and their evaluation concerning strontium-90 produced by nuclear weapons testing will be discussed by others at this hearing.

The external gamma exposures through September 1955 may be described briefly as follows:

"---With respect to the gamma dose, the average value for the United States is higher than it is for the rest of the world. The range of values in the United States is relatively narrow, 6 to 49 millirads, except for Salt Lake City (160), Grand Junction (120), and Albuquerque, N. M. (110). The representative dose for eastern United States is about 15 to 20 millirads, with slightly higher values in the Middle West and lower values on the West Coast.

The cumulative gamma dose at the foreign stations is in the range of 4 to 23 millirads, except for some of the Pacific islands, where the range is from 13 to 150 millirads.---"[25]

These are "infinity" doses, i.e., the maximum possible exposures one might receive if he were out-of-doors for the lifetime of the radioactivity, there were no weathering effects, and the activity decayed according to $(\text{time})^{-1.2}$. The actual radiation exposures will vary with changes in these conditions, but roughly may approximate one-half of the infinity dose.

In summarizing, the data on radiation exposures from fallout, the National Academy of Sciences - National Research Council Report said:[26]

"--- it may be stated that U. S. residents have, on the average, been receiving from fallout over the past five years a dose which, if weapons testing were continued at the same rate, is estimated to produce a total 30-year dose of about <u>one-tenth of a roentgen</u>; and since the accuracy involved is probably not better than a factor of five, one could better say that the 30-year dose from weapons testing if maintained at the past level would probably be larger than 0.02 roentgens and smaller than 0.50 roentgens.---

"The rate of fallout over the past years has not been uniform. If weapons testing were, in the future, continued at the largest rate which has so far occurred (in 1953 and 1955) then the 30-year fallout dose would be about twice that stated above.---"

Gamma radiation exposures near the Nevada Test Site are generally higher than the average for the United States. The map on page ____ shows the estimated gamma exposures accumulated from all tests at the Nevada Test Site. Table 10 lists all of the communities that have received sufficient fallout to result in an estimated 0.2 roentgens or more to the inhabitants. In addition to this list, the highest fallout level noted to date in an inhabited place around the Nevada Test Site occurred in 1953 at a motor court near Bunkerville, Nevada, where about 15 people might have accumulated 7 to 8 roentgens if they had continued to live there indefinitely.

The National Academy of Sciences - National Research Council Report recommended:[26]

"--- That for the present it be accepted as a uniform national standard that X-ray installations (medical and non-medical), power installations, disposal of radioactive wastes, experimental installations, testing of weapons, and all other humanly controllable sources of radiations be so restricted that members of our general population shall not receive from such sources an average of more than 10 roentgens, in addition to background, of ionizing radiation as a total accumulated dose to the reproductive cells from conception to age 30.---

"---That individual persons not receive more than a total accumulated dose to the reproductive cells of 50 roentgens up to age 30 years --- and not more than 50 roentgens additional up to age 40 ---"

The National Committee on Radiation Protection and Measurement[27] has recommended that, "The maximum permissible dose to the gonads for the population of the United States as a whole from all sources of radiation, including medical and other man-made sources, and background, shall not exceed 14 million rems per million of population over the period from conception up to age 30, and one-third that amount in each decade thereafter. Averaging should be done for the population group in which cross-breeding may be expected."[27]

Since natural background radiation is roughly four roentgens per 30 years, the value for man-made sources becomes about 10 million man-rems for a population of one million. This particular unit was selected because of genetic considerations, i.e., radiation doses to relatively large populations. The average exposure to only those communities around the Nevada Test Site that experienced the greatest amount of fallout (0.2 roentgens or more) is 0.6 roentgens for the six years since the regular nuclear tests were started. The round numbers are 58,000 man-roentgens for 100,000 people. If the area considered around the Nevada Test Site is enlarged to include 1,000,000 people the average exposure is about 0.1 roentgens for the six years, or at a rate of about 1/2 a roentgen per thirty years. This is 1/20 of the recommendation of the National Committee on Radiation Protection and Measurement for maximum exposures.

The highest measured concentration of fission product activity in the air off the Nevada Test Site was at St. George, Utah during the Spring 1953 test series, amounting to about 1.3 microcuries per cubic meter of air averaged over a 24-hour period. It was estimated that the radiation dose to the lungs from this activity was less than that delivered every month by naturally occurring radioactive isotopes in the air that we breathe.

The highest measured concentration of activity from fallout material in water off the controlled area was at Upper Pahranagat Lake, Nevada in the Spring of 1955 amounting to 1.4×10^{-4} microcuries per milliliter at 3 days after the detonation. This is 1/36 of the operational guide--an amount that is considered safe for continuous consumption.

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TABLE 1

ROUGH ESTIMATE OF REDUCTION IN GAMMA RADIATION WITHIN STRUCTURES

TYPE STRUCTURE	PERCENTAGE OF OUT-OF-DOORS LEVEL
ONE STORY FRAME HOUSE	
First Floor	50
Basement (Center)	10
Basement (Side)	< 10
MULTI STORY REINFORCED CONCRETE	
Lower Floors (Away from windows)	10
Basement	~ 0.1
SHELTER (equivalent to three feet of earth)	~ 0.1

TABLE 2

RADIATION EXPOSURE

I PERMISSIBLE DOSE TO RESCUE CREW Ⓐ (ROENTGENS)	II TIME OF INITIAL CONTACT WITH POPULACE (HRS. AFTER DETONATION)	III DOSE TO POPULACE WHILE WAITING RESCUE Ⓑ (ROENTGENS)	IV TOTAL RADIATION DOSE TO POPULACE Ⓒ (ROENTGENS)	V DOSE TO POPULACE WHILE WAITING RESCUE Ⓓ (ROENTGENS)	VI TOTAL RADIATION DOSE TO POPULACE Ⓒ (ROENTGENS)
100 r/hr Line					
25	5½	72	85	14	26
50	2½	40	65	8	33
100	1¼	10	60	2	52
300 r/hr Line					
25	16	320	332	64	76
50	8½	260	285	52	77
100	5	205	260	41	91
500 r/hr Line					
25	25	600	612	120	112
50	14	500	525	100	125
100	7¼	400	450	80	130

Ⓐ Based on a 2½ hour mission to rescue crew

Ⓑ Assuming ½ of out-of-doors exposure

Ⓒ Assuming populace receives ½ of exposure to rescue crew

Ⓓ Assuming 1/10 of out-of-doors exposure

TABLE THREE

APPROXIMATE AREAS ENCOMPASSED BY THE EFFECTIVE BIOLOGICAL ISODOSE LINES SHOWN IN THE MAP

Isodose Line (r)	Approximate Areas Encompassed (square miles)
50	25,000
100	12,500
400	5,000

TABLE FOUR

APPROXIMATE FISSION PRODUCT ACTIVITIES
(MICROCURIES PER MILLILITER OF GRAM x 10^2)
TO PRODUCE ONE RAD DOSE TO LOWER LARGE INTESTINE*

Duration of Ingestion (Days)	Start of Intake (Days after detonation)							
	1 (1st Hour)	2 (24th Hour)	3	4	5	10	15	20
1	35	2.5	1.9	1.7	1.4	1.1	1.1	1.0
2	24	1.7	1.1	0.89	0.81	0.62	0.57	0.53
3	15	1.3	0.82	0.65	0.56	0.41	0.40	0.37
4	13	1.0	0.65	0.53	0.46	0.33	0.30	0.29
5	12	0.9	0.57	0.44	0.39	0.28	0.25	0.22
10	9.2	0.64	0.40	0.29	0.25	0.17	0.14	0.13
15	7.8	0.53	0.33	0.26	0.21	0.13	0.11	0.097
20	7.5	0.49	0.29	0.21	0.18	0.11	0.089	0.079

* a. Activities computed at start of intake period.

b. Based on intake of 2200 milliliters or grams of water and food per day for adults.

TABLE FIVE

SOME POSSIBLE BIOLOGICAL EFFECTS FROM RADIATION DOSES TO SPECIFIC ORGANS *

Dose (Rads)	Gastrointestinal Tract	Thyroid	Bones
10,000		Minor changes in structure	
			Tumor production
	Permanent or serious damage -- survival threatened		
1,000	Tumor Production		
			Minor changes in structure
	Immediate effects such as nausea and vomiting		
		Potential carcinogenic dose to thyroids of few percent of children and adolescents	
100			

*Lesser short term effects would be expected from the same doses distributed in time.

TABLE 6

U.S. Public Health Service Monitoring Stations
During Operations PLUMBBOB
(Spring 1957)

Albany, New York
Anchorage, Alaska
Atlanta, Georgia
Austin, Texas
Baltimore, Maryland
Berkeley, California
Boise, Idaho
Cheyenne, Wyoming
Cincinnati, Ohio
Denver, Colorado
El Paso, Texas
Gastonia, North Carolina
Harrisburg, Pennsylvania
Hartford, Connecticut
Honolulu, T. H
Indianapolis, Indiana
Iowa City, Iowa
Jacksonville, Florida
Jefferson City, Missouri
Juneau, Alaska
Klamath Falls, Oregon
Lansing, Michigan
Lawrence, Massachusetts
Little Rock, Arkansas
Los Angeles, California
Minneapolis, Minnesota
New Orleans, Louisiana
Oklahoma City, Oklahoma
Phoenix, Arizona
Pierre, South Dakota
Portland, Oregon
Richmond, Virginia
Salt Lake City, Utah
Santa Fe, New Mexico
Seattle, Washington
Springfield, Illinois
Trenton, New Jersey
Washington, D. C.

TABLE 7

AEC Monitoring Stations
During Operation PLUMBBOB
(Spring 1957)

Berkeley, California	Radiation Laboratory, University of California
Cincinnati, Ohio	General Electric Company - Aircraft Nuclear Propulsion Department
Idaho Falls, Idaho	Idaho Operations Office
Lemont, Illinois	Argonne National Laboratory
Los Alamos, New Mexico	Los Alamos Scientific Laboratory
New York, New York	New York Operations Office
Richland, Washington	Hanford Operations Office
Oak Ridge, Tennessee	Oak Ridge National Laboratory
Rochester, New York	The Atomic Energy Project, University of Rochester
Salt Lake City, Utah	Radiobiology Laboratory, University of Utah
West Los Angeles, California	Atomic Energy Project, UC-Los Angeles

TABLE 8

U. S. Weather Bureau Fallout Sampling Stations in Operation During Operation PLUMBBOB
(Spring 1957)

Abilene, Tex.

Albany, N. Y.

Albuquerque, N. Mex.

Alpona, Mich.

Amarillo, Tex.

Atlanta, Ga.

Bakersfield, Calif.

Baltimore, Md.

Billings, Mont.

Binghamton, N. Y.

Bishop, Calif.

Boise, Idaho

Boston, Mass.

Buffalo, N. Y.

Caribou, Me.

Casper, Wyo.

Charleston, S. C.

Cheyenne, Wyo.

Chicago, Ill.

Cleveland, Ohio

Colorado Springs, Colo.

Concord, N. H.

Corpus Christi, Tex.

Concordia, Kan.

Dallas, Tex.

Del Rio, Tex.

Denver, Colo.

Des Moines, Iowa

Detroit, Mich.

Elko, Nev.

Ely, Nev.

Eureka, Calif.

Fargo, N. Dak.

Flagstaff, Ariz.

Fort Smith, Ark.

Fresno, Calif.

Goodland, Kans.

Grand Junction, Colo.

Grand Rapids, Mich.

Green Bay, Wisc.

Hatteras, N. C.

Helena, Mont.

Huron, S. Dak.

Jackson, Miss.

Jacksonville, Fla.

Kalispell, Mont.

Knoxville, Tenn.

Las Vegas, Nev.

TABLE 8 (continued)

U. S. Weather Bureau Fallout Sampling Stations in Operation During Operation PLUMBBOB (Spring 1957)

Los Angeles, Calif.

Louisville, Ky.

Lynchburg, Va.

Marquette, Mich.

Medford, Oreg.

Memphis, Tenn.

Miami, Fla.

Milford, Utah

Milwaukee, Wisc.

Minneapolis, Minn.

Mobile, Ala.

Montgomery, Ala.

New Haven, Conn.

New Orleans, La.

New York (La Guardia), N. Y.

Philadelphia, Pa.

Phoenix, Ariz.

Pittsburgh, Pa.

Pocatello, Idaho

Port Arthur, Tex.

Portland, Oreg.

Prescott, Ariz.

Providence, R. I.

Pueblo, Colo.

Rapid City, S. Dak

Reno, Nev.

Rochester, N. Y.

Roswell, N. Mex.

Sacramento, Calif.

Salt Lake City, Utah

San Diego, Calif.

San Francisco, Calif.

Scottsbluff, Nebr.

Seattle, Washington

Spokane, Wash.

St. Louis, Mo.

Syracuse, N. Y.

Tonopah, Nev.

Tucson, Ariz.

Washington, D. C.(Silver Hill,Md.

Wichita, Kans.

Williston, N. Dak.

Winnemucca, Nev.

Yuma, Ariz.

TABLE 9

Foreign Monitoring Stations
During Operation PLUMBBOB
(Spring 1957)

Addis Ababa, Ethiopia

Anchorage, Alaska

Bangkok, Siam

Beirut, Lebanon

Belem, Brazil

Bermuda

Buenos Aires, Argentina

Canal Zone

Canton Island

Churchill, Manitoba, Canada

Clarke AFB, Philippines

Colombo, Ceylon

Dakar, French West Africa

Deep River, Ottawa, Ontario, Canada

Dhahran, Saudi Arabia

Durban Natal, South Africa

Edmonton, Alberta, Canada

Fairbanks, Alaska

French Frigate Shoals

Goose Bay, Labrador

Guam

Hilo, Hawaii

Hiroshima, Japan

Honolulu, Hawaii

Iwo Jima

Johnson Island

Juneau, Alaska

Keflavik, Iceland

Koror

Kwajalein

La Paz, Bolivia

Lagens, Azores

Lagos, Nigeria

Leopoldville, Belgian Congo

Lihue

Lima, Peru

Melbourne, Australia

Mexico City, Mexico

Midway Island

Milan, Italy

Misawa, Japan

Moncton, New Brunswick, Canada

(continued)

TABLE 9 (continued)

Foreign Monitoring Stations
During Operation PLUMBBOB
(Spring 1957)

Monrovia, Liberia

Montreal, Quebec, Canada

Moosoonee, Ontario, Canada

Nagasaki, Japan

Nairobi Kenya, East Africa

Nome, Alaska

North Bay, Ontario, Canada

Noumea, New Caledonia

Oslo, Norway

Ponape

Prestwick, Scotland

Pretoria, South Africa

Quito, Ecuador

Regina, Saskatchewan, Canada

Rhein Main, Germany

San Jose, Costa Rica

San Juan, Puerto Rico

Sao Paulo, Brazil

Seven Islands, Quebec, Canada

Sidi Slimane, French Morocco

Singapore

Stephenville, Newfoundland

Sydney, Australia

Tai Pei, Formosa

Thule, Greenland

Tokyo Air Base, Japan

Truk

Wake Island

Wellington, New Zealand

Wheelus AFB, Tripoli

Winnipeg, Manitoba, Canada

Yap

TABLE 10

ESTIMATED RADIATION EXPOSURES FOR COMMUNITIES AROUND THE NEVADA TEST SITE

Nevada

Name	Roentgen	Name	Roentgen
Acoma	3.0	Lincoln Mine	4.0
Alamo	1.3	Lockes Ranch	1.3
Ash Springs	0.6	Logandale	0.4
Baker	0.8	Lund	0.8
Barclay	2.0	Mesquite	1.8
Buckhorn Ranch	0.9	McGill	0.4
Bunkerville	4.3	Moapa	0.8
Caliente	0.7	Nellis AF Base	0.05
Carp	3.6	North Las Vegas	0.2
Clarks Station	0.8	Nyala	1.7
Crestline	0.7	Overton	0.35
Crystal	4.0	Pahrump	0.2
Crystal Springs	1.0	Panaca	0.65
Currant	0.5	Pioche	0.7
Dry Lake	1.0	Preston	0.7
Duckwater	0.8	Reed	4.0
East Ely	0.6	Rox	3.0
Eden Creek Ranch	0.7	Ruth	0.5
Elgin	3.5	Sharp's (Adaven)	1.2
Ely	0.6	Shoshone	0.7
Eureka	0.2	Sunnyside	1.2
Fallini Ranch	0.8	Ursine	0.6
Glendale	0.7	Warm Springs	0.5
Groom	2.0	Warm Spring Ranch	1.0
Hiko	1.0		
Kimberley	0.5		
Las Vegas	0.2		

Utah

Alton	0.8	Garrison	0.7
Anderson Junction	1.2	Glendale	1.2
Bear Valley Junction	0.4	Gunlock	2.6
Beaver	0.25	Hamilton Fort	0.6
Beryl	0.5	Hurricane	4.2
Beryl Junction	1.0	Kanab	1.6
Cedar City	0.4	Kanarraville	1.2
Enterprise	0.7	Leeds	3.0

Table 10 (continued)

Utah (continued)

Long Valley	0.8	Rockville	3.0
Lune	0.5	Saint George	3.0
Minersville	0.2	Santa Clara	3.5
Modena	0.5	Shivwits	2.8
Mount Carmel	0.85	Springdale	2.6
New Castle	0.6	Toquerville	2.0
New Harmony	1.2	Veyo	2.0
Orderville	1.5	Virgin	1.5
Panguitch	0.2	Washington	3.0
Paragonah	0.4	Zane	0.3
Parowan	0.4		
Pintura	1.2		

Arizona

Beaver Dam	2.0	Short Creek	1.6
Littlefield	1.6	Wolf Hole	1.3

Figure 1

GENERALIZED CONCEPTS: DIMENSIONS OF CLOUD AND STEM DISTRIBUTION OF ACTIVITY

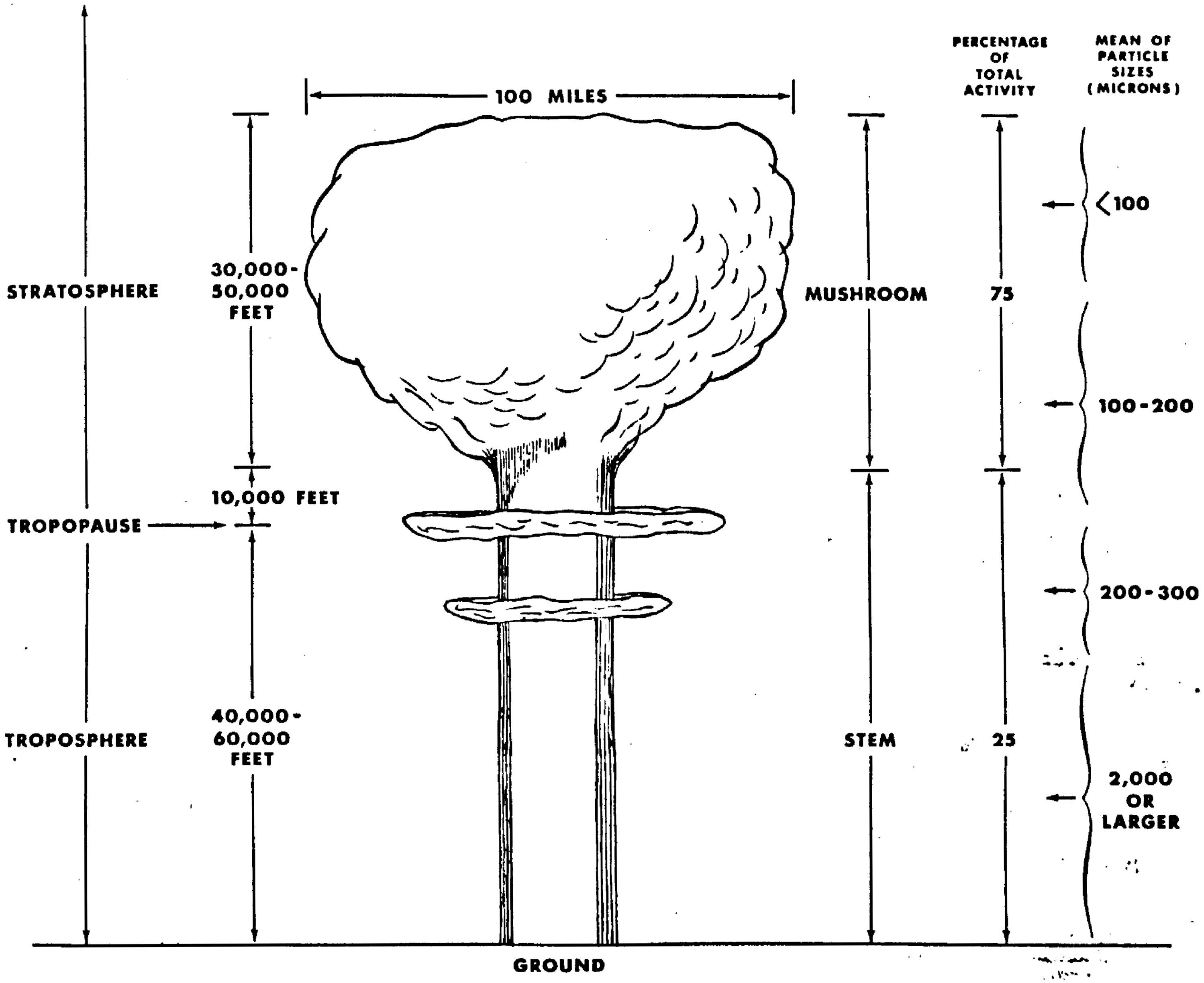
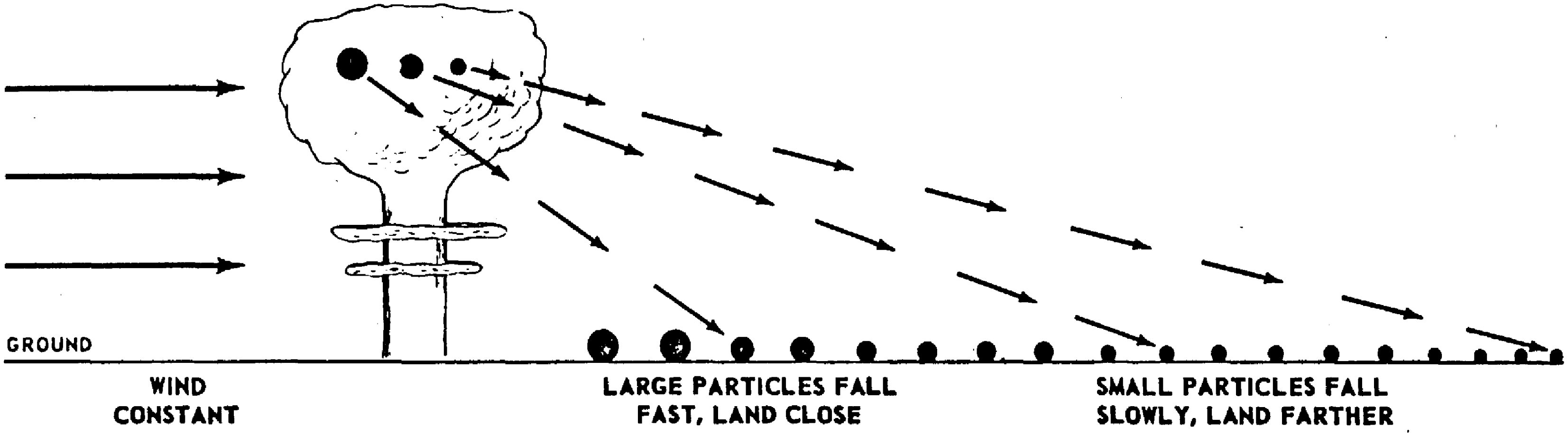


Figure 2a

FACTORS AFFECTING DISTRIBUTION OF FALLOUT *

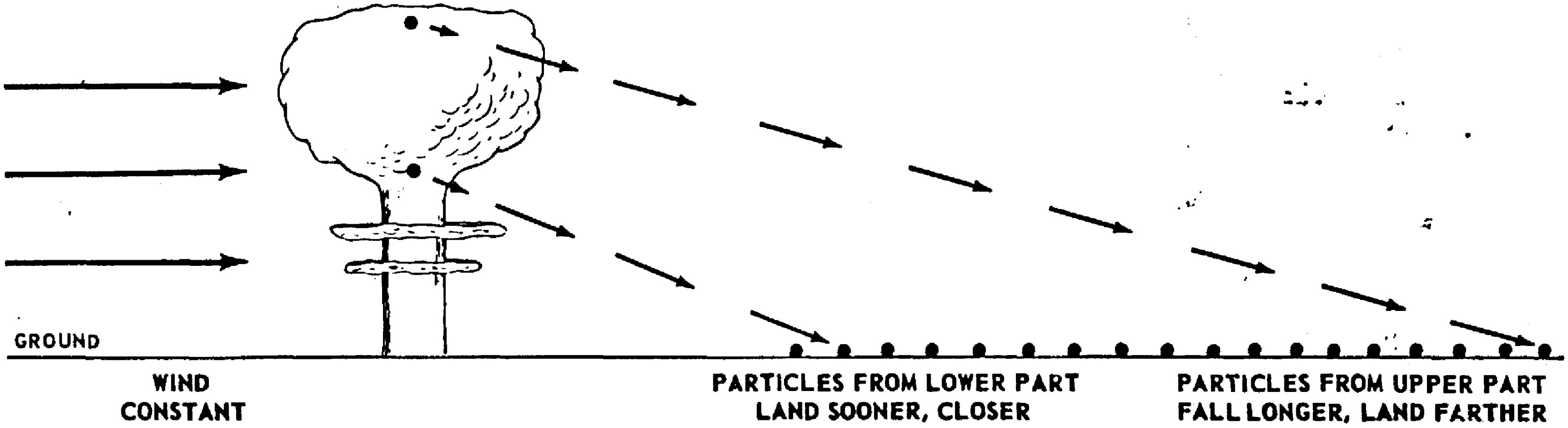
EFFECT OF PARTICLE SIZE

(WIND AND INITIAL HEIGHT ASSUMED CONSTANT)



EFFECT OF HEIGHT

(WIND AND PARTICLE SIZE ASSUMED CONSTANT)



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* As suggested in Civil Defense Technical Bulletin TB-11-21, Fallout and The Winds, October, 1955.

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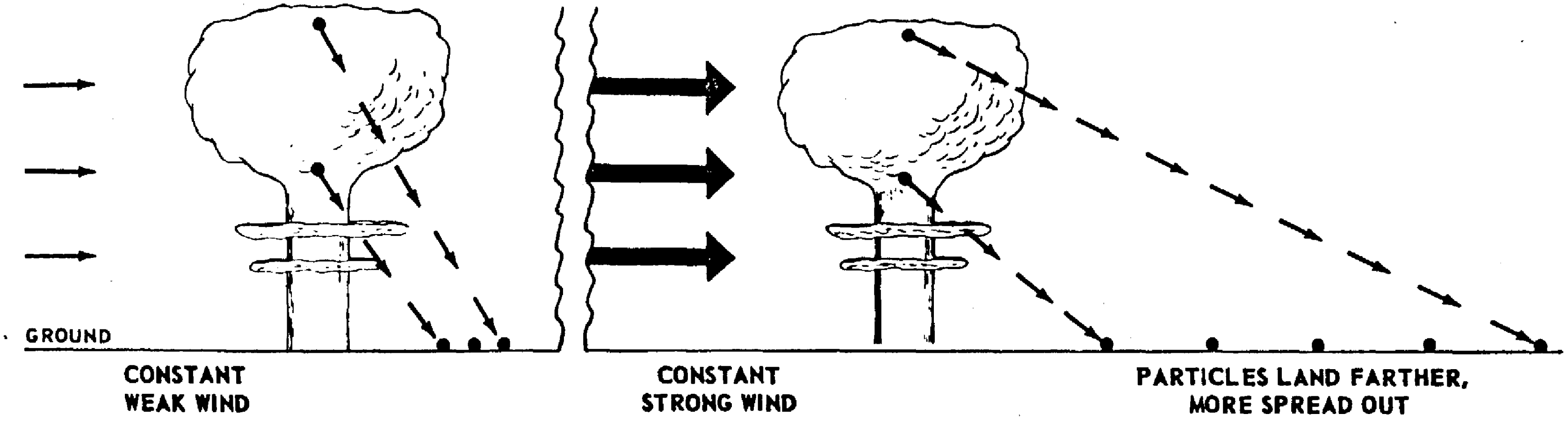
Figure 2b

FACTORS AFFECTING DISTRIBUTION OF FALLOUT *

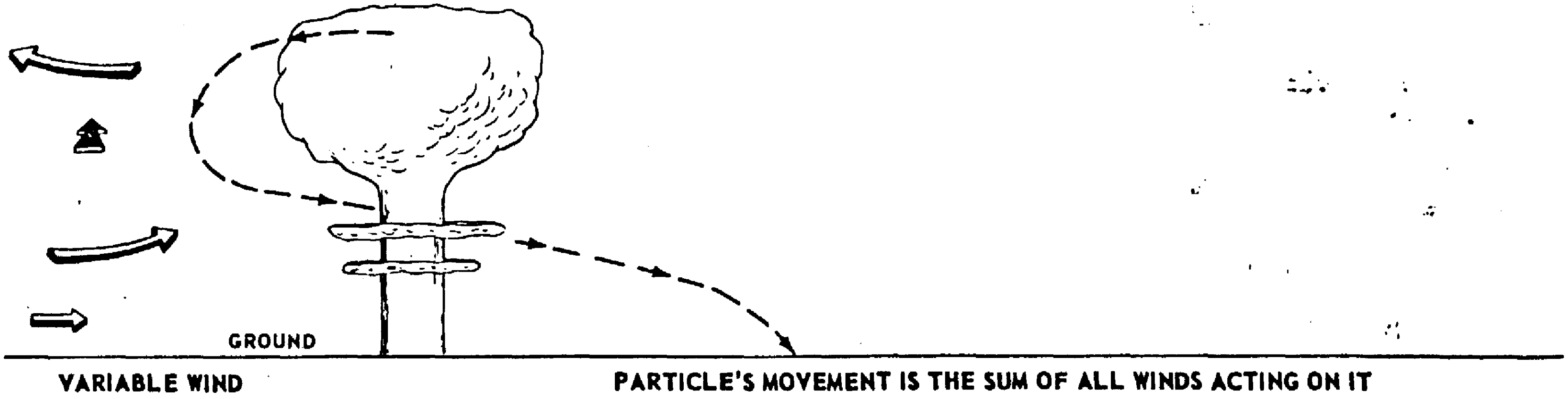
EFFECT OF WIND

(PARTICLE SIZE ASSUMED CONSTANT)



EFFECT OF VARIABLE WIND

(PARTICLE SIZE AND INITIAL HEIGHT ASSUMED CONSTANT)



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* As suggested in Civil Defense Technical Bulletin TB-11-21, Fallout and The Winds, October 1955.

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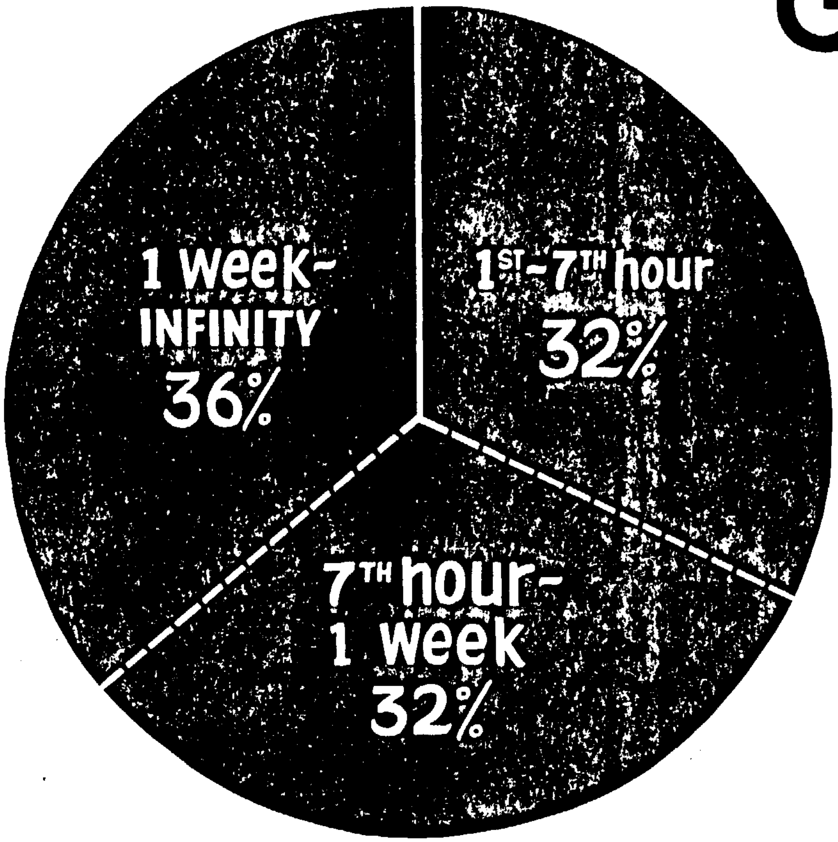
Theoretical Accumulated GAMMA DATA*

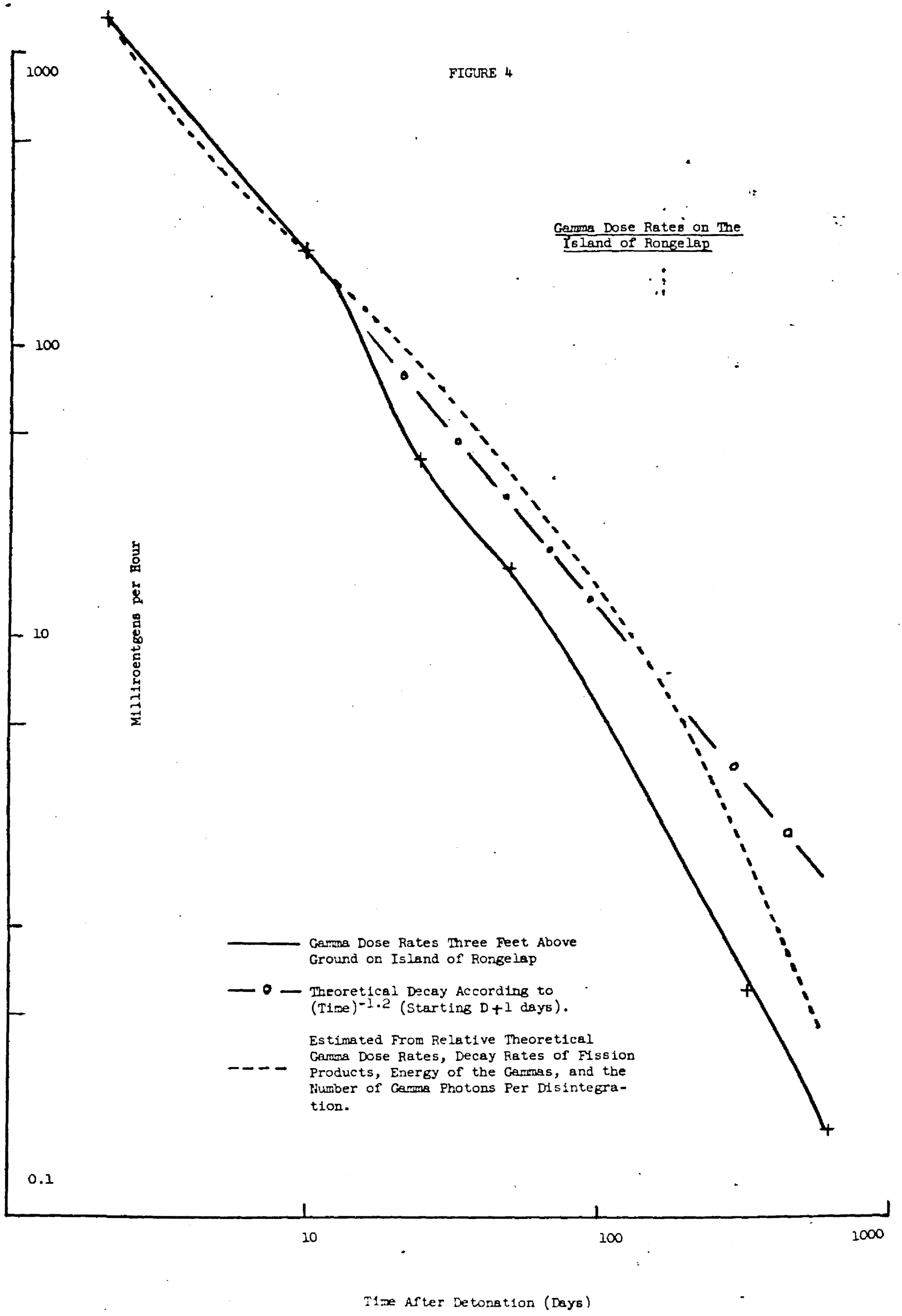


*ASSUMPTION

1. Fallout occurred at one hour after detonation.
2. Radiological decay followed (time)-1.2
3. No shielding or weathering effects.

FIGURE 3

FIGURE 4



Gamma Dose Rates on The Island of Rongelap

Figure 5

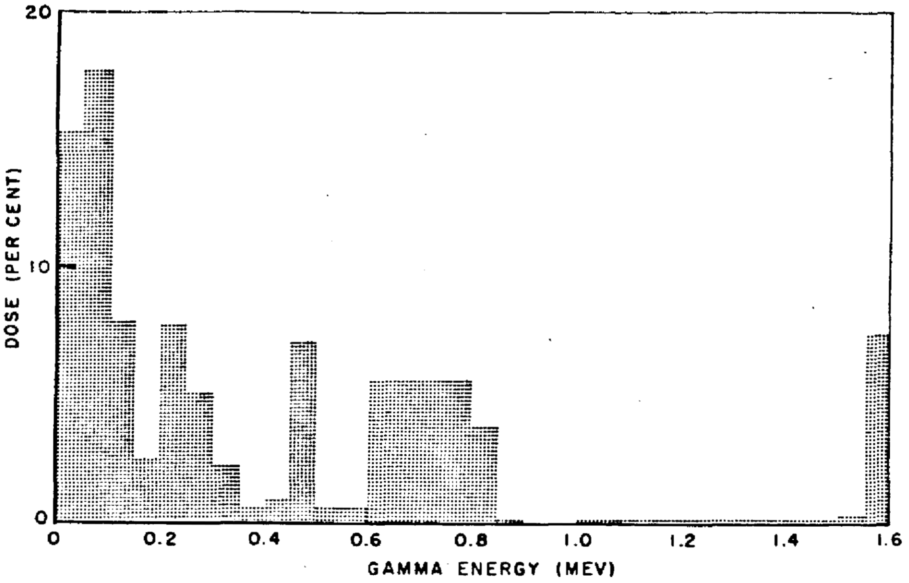
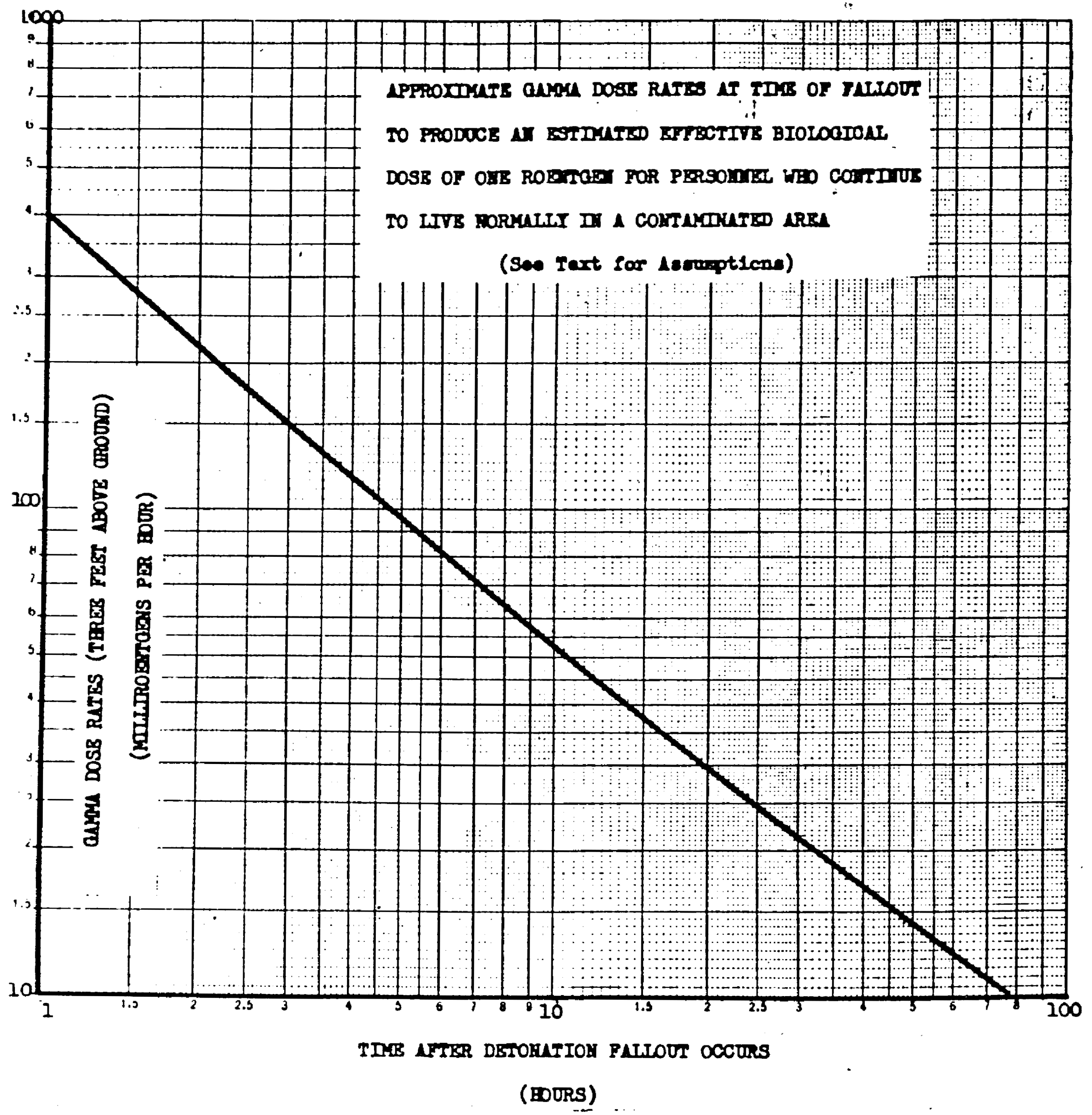


FIGURE 6


APPROXIMATE GAMMA DOSE RATES AT TIME OF FALLOUT
TO PRODUCE AN ESTIMATED EFFECTIVE BIOLOGICAL
DOSE OF ONE ROENTGEN FOR PERSONNEL WHO CONTINUE
TO LIVE NORMALLY IN A CONTAMINATED AREA
(See Text for Assumptions)
GAMMA DOSE RATES (THREE FEET ABOVE GROUND)
(MILLIROENTGENS PER HOUR)
1000
9
8
7
6
5
4
3
2.5
2
1.5
100
8
7
6
5
4
3
2
1.5
10
1
1.5
2
2.5
3
4
5
6
7
8
9
10
1.5
2
2.5
3
4
5
6
7
8
100
TIME AFTER DETONATION FALLOUT OCCURS
(HOURS)

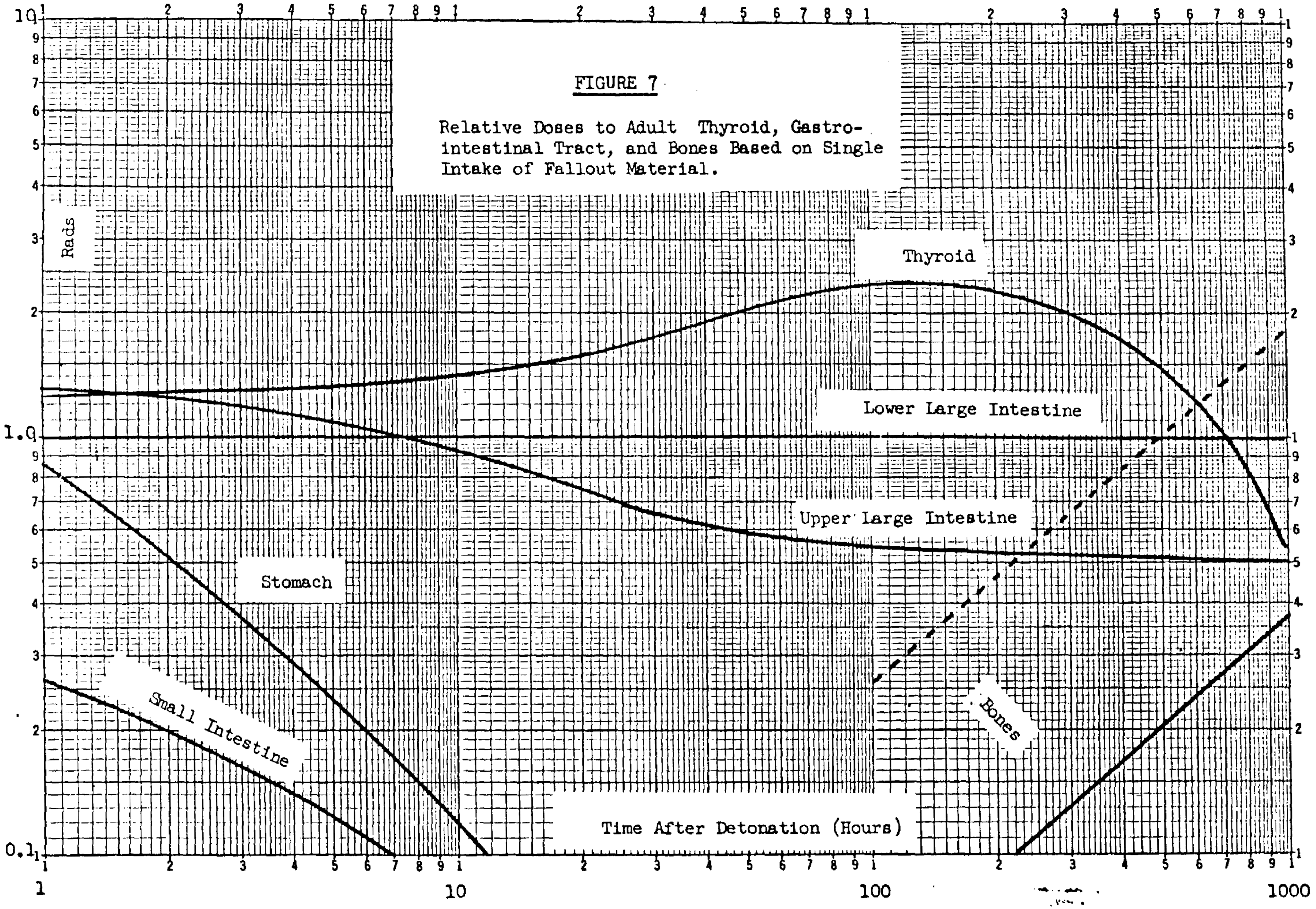
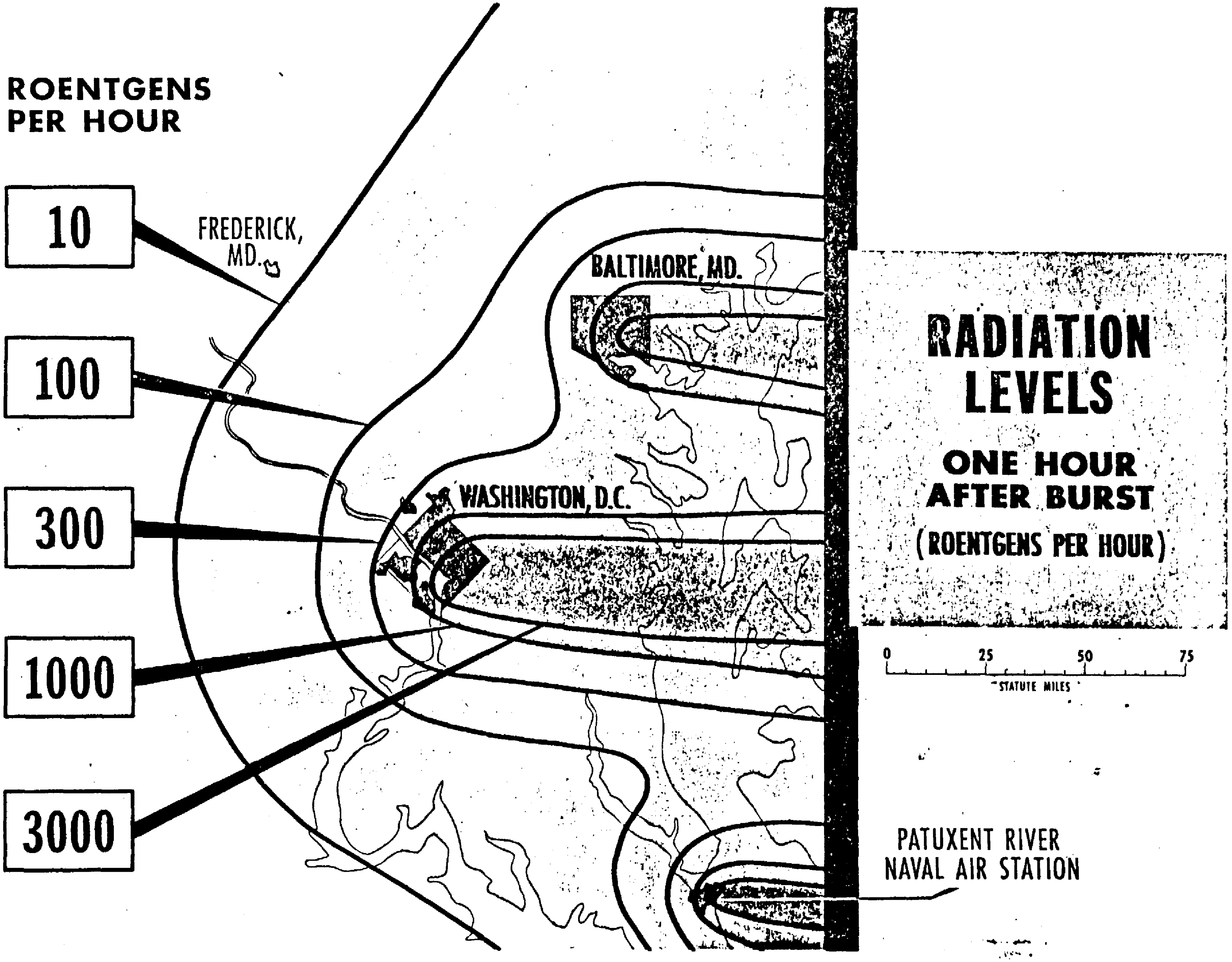


FIGURE 7

Relative Doses to Adult Thyroid, Gastrointestinal Tract, and Bones Based on Single Intake of Fallout Material.

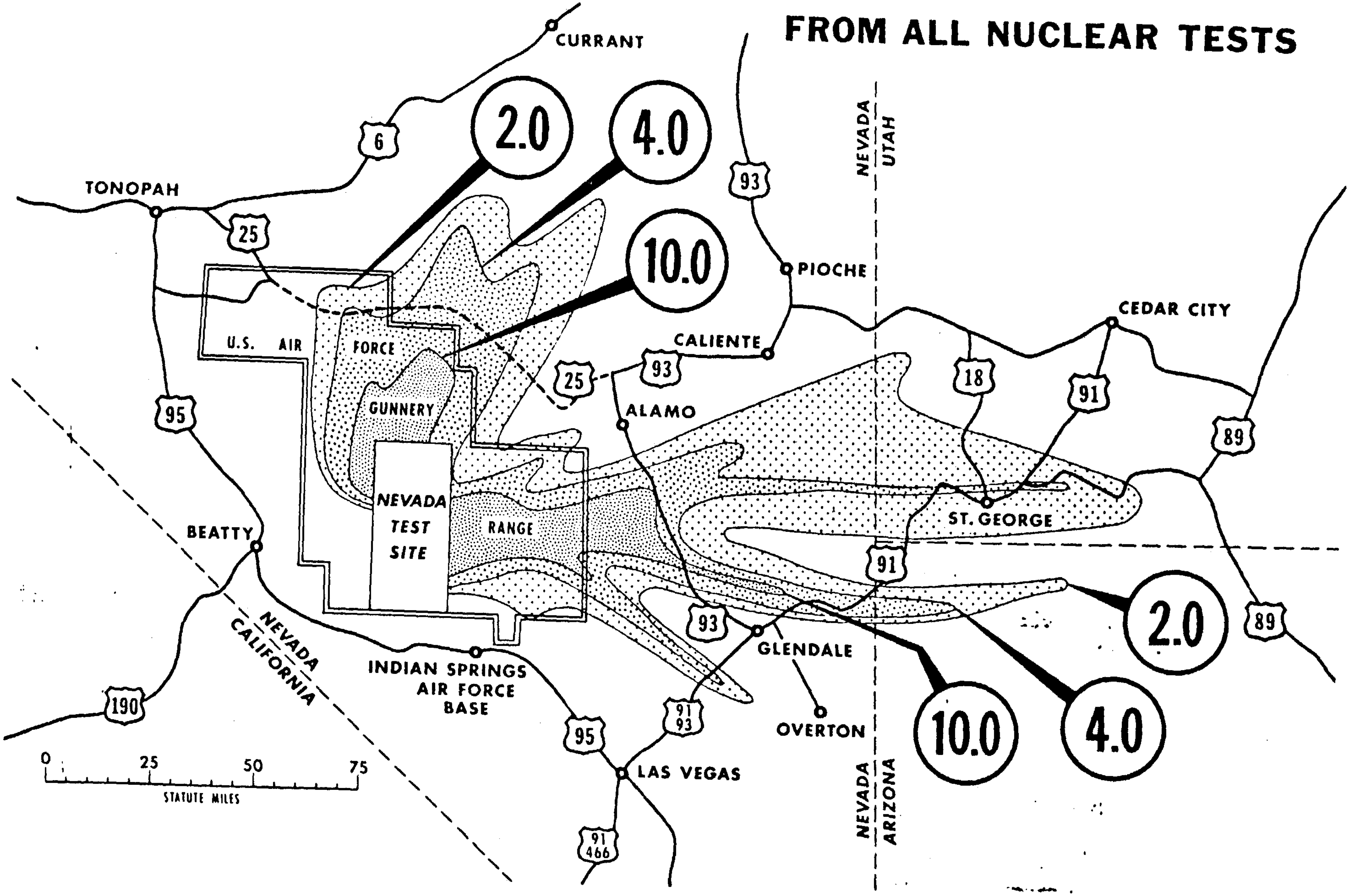


RADIATION LEVELS

ONE HOUR AFTER BURST

(ROENTGENS PER HOUR)

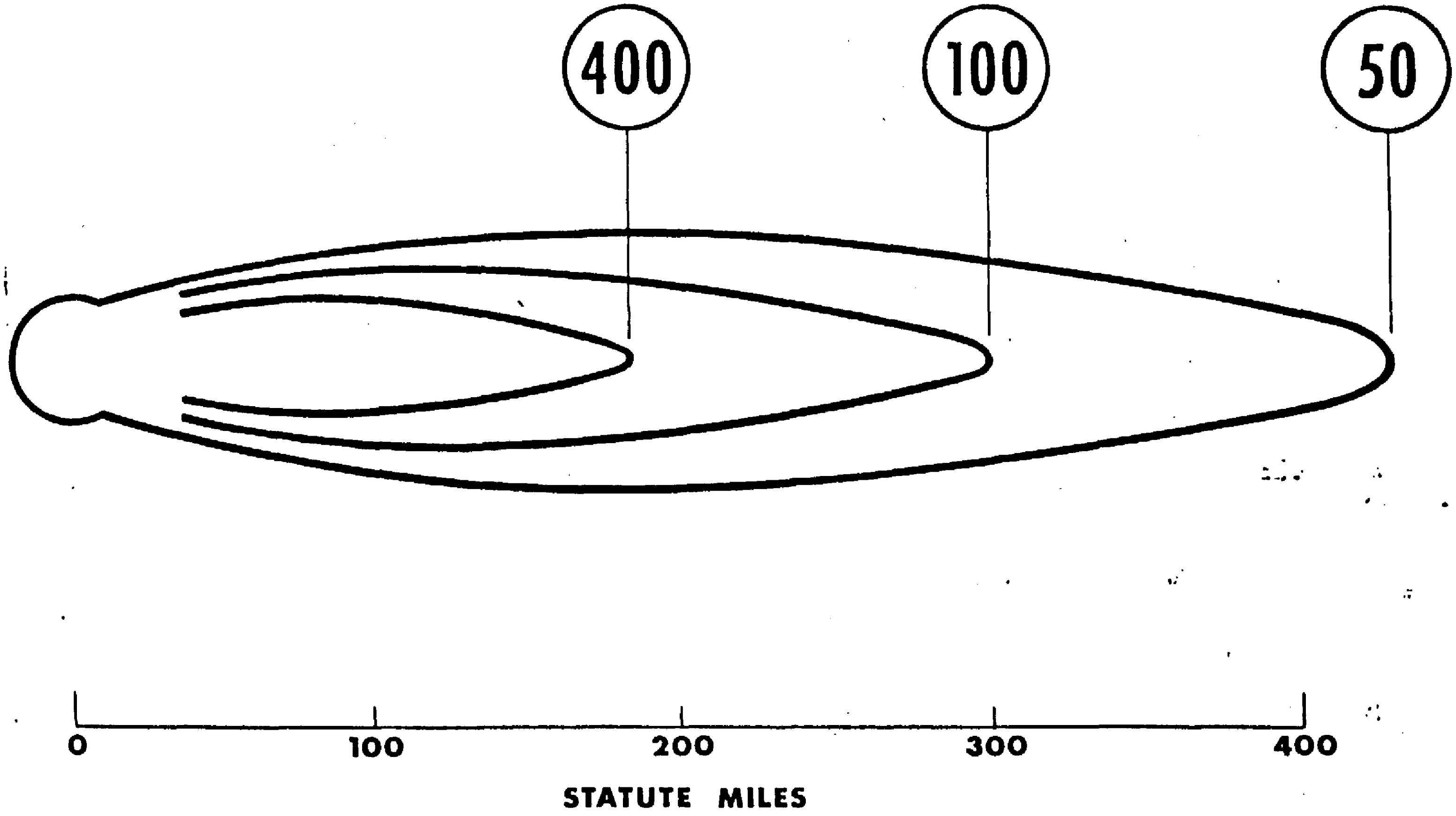
ESTIMATED RADIATION DOSES (Roentgens) FROM ALL NUCLEAR TESTS



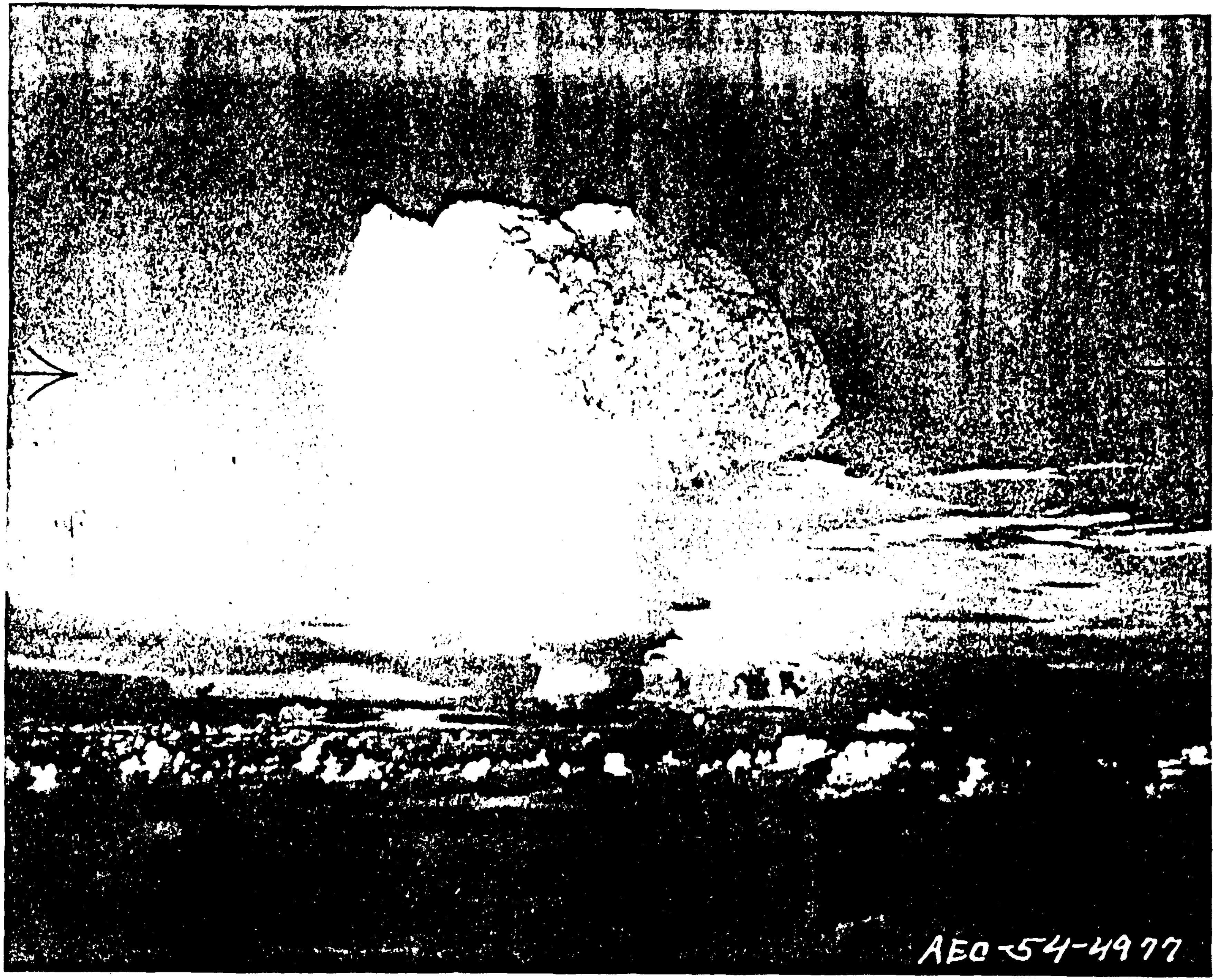
IDEALIZED FALLOUT DIAGRAM

BASED ON MARCH 1, 1954 HIGH-YIELD NUCLEAR DETONATION

ISODOSE LINES ARE EFFECTIVE BIOLOGICAL DOSES (ROENTGENS)



(SEE TEXT FOR ASSUMPTIONS)


AEO-54-4977