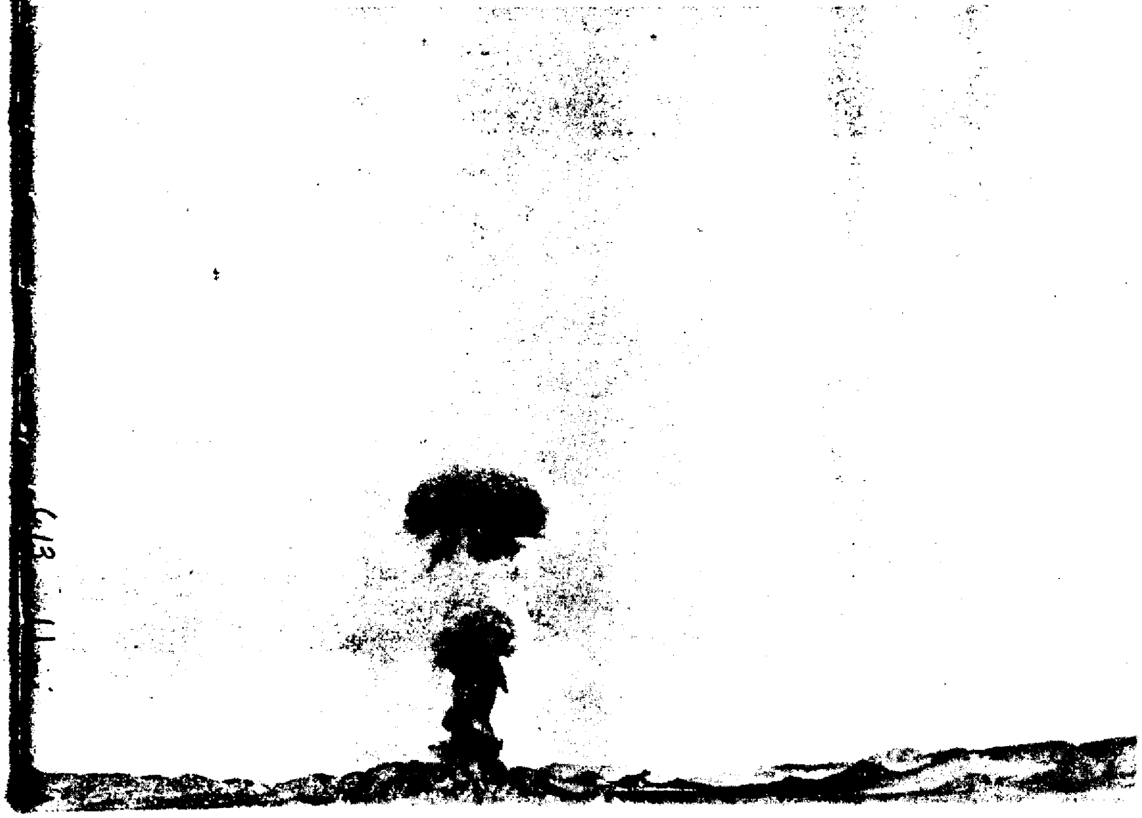
RR NO.
20234

HEALTH ASPECTS OF NUCLEAR WEAPONS TESTING

ATOMIC ENERGY COMMISSION
UNITED STATES OF AMERICA

June 1964



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PREFACE

The signing of the Limited Test Ban Treaty in September 1963 marked the close of 14 years of atmospheric nuclear weapons testing spread over an 18-year period. However, it did not mark the end of a need for further information and interpretation of data concerning the health aspects of nuclear weapons testing.

This pamphlet is concerned principally with the health aspects of nuclear weapons testing in the atmosphere. Nothing new is contained herein and much has been omitted for brevity. The pamphlet does attempt to bring together the highlights of a large body of information and thus in some small way may assist in further enlightenment of a complex subject.

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INTRODUCTION

Fallout from nuclear weapons tests has been by far the principal man-made source of radioactive environmental contamination. About 340 nuclear detonations in the atmosphere, by all nations testing, have been announced. The total energy release has been about 511 million tons (MT) equivalent of TNT with the U.S.S.R. tests accounting for about 70 percent of the total.[1] Included in this total is about 193 million tons of energy released by fission—the process that creates the radioactive fission products present in fallout.[1] Two hundred million tons of TNT energy equivalent would produce about 12 tons, by weight, of fission product debris.

The discussion that follows in section I attempts to summarize an enormous amount of data and to present some evaluation of the estimated radiation exposures to persons from radioactive fallout. Section II deals with other health aspects of nuclear weapons testing.

The information presented herein is intended to provide some answers to three basic questions concerning the testing of nuclear weapons:

1. What are the problems and possible risks associated with nuclear weapons testing?
2. What are the data concerning effects from past tests?
3. What do these data mean—how serious are the possible risks?

With these three questions in mind, the information for each health aspect—such as whole body exposures—is presented under three subheadings, i.e., Background Information, The Data, and Evaluations.

LOCATIONS of NUCLEAR WEAPONS TEST SITES

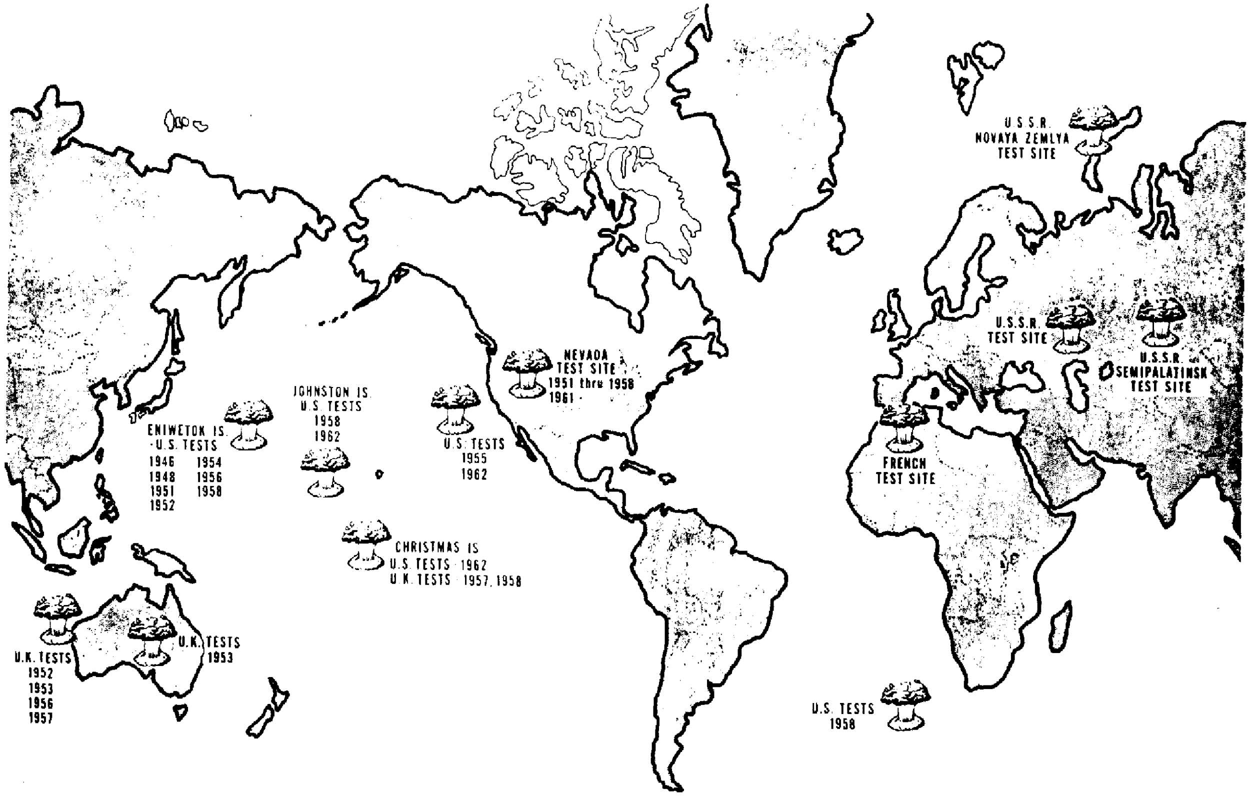

FIGURE 1.

SECTION I.

RADIATIONS

A. GENERAL BACKGROUND INFORMATION

1. Natural Background and Medical Exposures

As far as is known, man always has and always will live in an environment filled with nuclear radiation. There are radioactive materials present naturally in the ground, the sea, and in the air. Cosmic rays bombard us from outer space. Naturally occurring radioactive materials in our food supply irradiate us from within.

To these levels of radiation exposures are now added those from fallout – but these radiations (gamma rays and beta particles) are no different in kind from those emanating from natural sources. Nor is there any evidence that they produce any fundamentally different biological effects. The radiations from natural sources and from medical, industrial, and scientific uses of radioisotopes and X-ray machines, and their biological effects, have been studied intensively for many years.

To repeat, radiation exposures from fallout are in addition to those from natural sources but they are just that – additions of more of the same type of radiation. Fallout has not introduced a new and strange agent into our environment with completely unpredictable results. Indeed, a Committee of the National Academy of Sciences-National Research Council has stated: " . . . Despite the existing gaps in our knowledge, it is abundantly clear that radiation is by far the best understood environmental hazard . . ."[2]

TABLE 1. – Radiation Exposures from Natural Background and Medical Sources

Natural Background (annual exposures)	*Roentgens*
Total	0.085–0.20
Gamma rays (from terrestrial sources) and cosmic rays	0.1 (varies).
Potassium 40 (internal)	0.018 (varies).
Carbon 14	0.001
Medical Exposures	
Chest X-ray (per exposure)	0.2
Back X-ray (per exposure)	0.4
Photofluorogram (per exposure) about	0.5–2.0
Gastro-intestinal series about	30.

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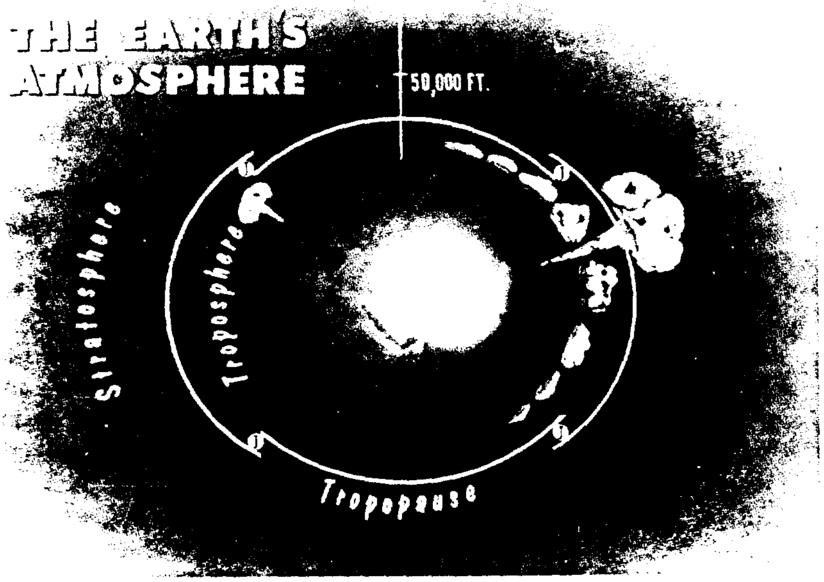
Various units have been used to express exposure to radiation such as the roentgen, rep, rem, and rad. All are intended to express some relationship between the radiation energy absorbed and biological effects. Since it is not critical for the following discussions to understand the technical differences among the units, only the "roentgen" will be used. To provide some perspective as to the magnitude of the "roentgen" table I is included.

2. Sources and Nature of Fallout

The major source of radioactive materials in fallout is the fissioning or splitting of atoms of uranium and plutonium that gives rise to a large number of unstable radioisotopes. In the fusion process hydrogen nuclei are joined together. Induced radioactive products result when inert materials capture neutrons that are released during either the fission or fusion process. Generally, these induced radioactive materials are relatively short-lived and contribute only in a minor way to radiation exposures to man. The principal exception is carbon 14 described in section I F (page 16).

Some of these radioactive materials escape as gases and are dispersed and diluted in the atmosphere. Most of the fission products, however, become incorporated into or attached onto minute inert particles of dust and debris from the immediate environment of the bomb. The dust particles, together with the associated radioactive nuclides, are swept high into the air by the heat and force of the nuclear explosion. The larger particles and those in the lower levels of the cloud fall nearby. Smaller particles in the upper levels are carried away to be spread worldwide. The worldwide distribution of these radioactive particles follows the same pattern as would occur with any other small particles injected into the same regions of the atmosphere – radioactivity has essentially no effect on the pattern of distribution.

Roughly, a nuclear detonation of one-half million tons or less, fired at a low altitude – but high enough so the fireball does not intersect the ground – results in most of the fission products remaining in the lower atmosphere, the troposphere. They are deposited on the earth's surface at a rate such that one-half of the amount remaining in the atmosphere at any one time falls in 2–4 weeks (called tropospheric residence half-time). As the energy yields of the nuclear detonations increase, more and more of the fission products are swept higher and higher into the stratosphere – the layer above the troposphere (fig. 2). The residence half-time here is more like one-half a year for injection into the lower stratosphere in the polar



U.S. WEATHER BUREAU PHOTO

FIGURE 2.—Generalized drawing of the earth's atmosphere.

regions and one year or somewhat less at the equator. Radioactive debris from nuclear detonations occurring at very high altitudes (about 30 miles and higher) may have a residence half-time of five years or more.

Roughly two-thirds of the radioactive particulate debris injected into the lower stratosphere at the north polar regions has been observed to fall in the 30°–60° North latitude zone, where about 80 percent of the world's population live. Injection at the equatorial regions has been observed to result in a more even distribution between the two hemispheres.

For surface bursts of high (million ton range) yield about 50–80 percent of the radioactive debris is deposited as "early fallout," i.e., within 24 hours. Air bursts—where the fireball does not approach the surface—result in little, if any, local fallout.

Table 2 tabulates some of the key data on estimated nuclear energy yields from all past nuclear weapons tests. Of the total energy released of 511 million tons equivalent of TNT about 70

TABLE 2.—Estimates of Yields from All Nuclear Weapons Tests

	USSR	*US and UK*	*Total*†
Total million tons*	350	161	511
Fission million tons	111	82	193
Fission million tons scattered globally	110	51	161

*TNT equivalent.

†The French tests have contributed only small amounts.

percent resulted from U.S.S.R. tests. This total energy release is of use in estimating the amount of carbon 14 produced. Incidentally, it is assumed that the carbon 14 is distributed more or less uniformly around the world.

Table 2 also shows that of the 193 million tons energy equivalent releasing fission products, about 161 million tons were scattered globally.[3] Approximately two-thirds of this amount originated from U.S.S.R. tests but will account for about three-quarters of the long-term fallout in the United States because of meteorological factors. This is because there will be more deposition in the North Temperate Zone from a nuclear detonation in the lower atmosphere at a northerly latitude than from the same shot at an equatorial site. Atmospheric tests at the Nevada Test Site have contributed very little to the deposition of long-lived radioisotopes but at times have been the source of relatively high amounts of short-lived radioactive materials including iodine 131 in the local environment.

At the time of a nuclear detonation something like 200 different radioactive substances are formed by fission. Additional ones are created by induced activity. Although these materials emit only radiations with which we are already familiar—gamma rays and beta particles—it appears at first glance to be almost an impossible task to consider them individually and in the aggregate for an appraisal of their health hazard. Fortunately, for an analysis of the problem, most of the radionuclides are of little health consequences because of their short radioactive half-lives or other characteristics such as being highly insoluble. In fact, it is possible to estimate the radiation doses to various organs of the body by considering only five principal radionuclides in fallout that are deposited internally, i.e., iodine 131, strontium 90, strontium 89, cesium 137 and carbon 14. To these internal doses there must be added those to the whole body due to the radiations from fallout material outside the body. The problem of estimating these latter radiation doses is again simplified by considering first cesium 137 and then lumping all of the remaining radionuclides together in the calculations.

B. WHOLE BODY EXPOSURES

Background Information

Fallout particles consisting of inert materials together with the associated radioactive materials settle to the earth's surface where most of them remain and thus never get inside our bodies. These external, man-made radionuclides, however, will irradiate the whole body by their penetrating gamma radiations while their shorter range beta particles will contribute a much less biologically significant exposure to the skin.

Of the radionuclides that contribute to external radiation, the most important single one is cesium 137. Its radioactive half-life is approximately 30 years. Thus, it is possible for cesium 137 to remain in our environment for long periods of time without losing much of its activity, although there can be loss or reduction in availability of the material through normal weathering processes. Still cesium 137 does have a short enough half-life so that most of the radiations are released within the lifetime of a man.

All radioactive materials in fallout, except cesium 137, which remain outside the body may be conveniently lumped together to estimate their contribution to external exposures. These usually are called "short-lived" even though some do have half-lives of upwards of one year. In spite of the fact that nearly all of the radiation exposure received from these short-lived radionuclides is completed within a year after the radionuclides are created the total amount of exposure during the year may be greater than that received from cesium 137 within 30 years.

Cesium 137 also is one of the two (carbon 14 is the other) principal radionuclides deposited internally that irradiate the whole body. It is not a major source of the total whole radiation dose except in such cases as that of Eskimos whose diet is largely caribou or reindeer meat. The food chain (lichen-caribou-Eskimo) reflects the relatively high surface contamination of cesium 137 on the lichens.

The Data

The highest whole body exposures from nuclear weapons tests ever reported by the United States were about 175 roentgens to 64 Marshallese following the March 1, 1954 surface nuclear test detonation at the Pacific Proving Ground.[4] This situation resulted from a shifting of the winds so that the local heavy fallout from this large yield surface burst occurred, in part, across the islands instead of the open sea.

The Marshallese were evacuated, given medical treatment and returned to their home island of Rongelap on June 29, 1957 after radiation levels had subsided to acceptable levels[5] (fig. 3). From 1956 to 1962 about 24 children have been born—all normal—and four persons have died from natural causes.[6] (One of these had been on another island and received 69 roentgens exposure.) Four deaths have occurred in the comparison population of like size. There were, of course, noticeable effects immediately after the irradiation such as nausea and

HOLMES AND NARVER PHOTO

FIGURE 3.—Rongelapese returned to their home island June 1957. Structures were newly built by the U.S. Government.

itching of the skin (see section on Skin Exposure below, section I C page 8).

Also, there were definite changes in levels of blood constituents for months afterwards. The Marshallese have been examined by a team of physicians yearly and to the present time no statistical differences have appeared between them and the "control" group for such factors as birth and death rates, life-shortening, leukemia, cataracts or cardiovascular, arthritic, ophthalmic, or dental defects. There may be a suggestion of greater incidence of miscarriages and stillbirths and more recent data indicate that there may be a lag in growth and development of the children, but the paucity of vital statistics and the small number of persons involved preclude a determinnation.

It was reported by the Japanese that some fishermen aboard a vessel near the Pacific Proving Ground on the same date may have received a higher exposure than the Marshallese.[7] One of these fishermen died on September 23, 1954 of a liver disorder complicated by the development of jaundice and pneumonia.[8]

The highest estimated exposure to any individual near the Nevada Test Site was 13.5 roentgens and the next highest 10.5 roentgens. The highest estimated exposure to any community was about 6 roentgens. There were about 30 persons who received exposures between 6 and 10.5 roentgens. All of the above radiation doses are accumulated doses since the Nevada Test Site opened in 1951.[9]

Having delineated these highest exposures it is proper to discuss "average" exposures since these have relevance for evaluating possible genetic effects. The average whole body exposure to persons in the United States (to be accumulated over 30 years) from all past nuclear detonation tests of United States, United Kingdom and U.S.S.R. (the French tests contributed very little) has been estimated to be 110 milliroentgens* (0.11 roentgens).[1] Somewhat over one-half of this exposure will result from radioactive fallout materials outside the body. The remainder is due to carbon 14 and cesium 137 deposited internally following ingestion (inhalation contributes negligible amounts).

In the case of the Eskimos, the highest measured amount of externally deposited cesium 137 in any individual was in June 1963.[10] This highest quantity of cesium 137 would produce a dose *rate* of about 190 milliroentgens (0.19 roentgen) per year at the time of measurement. The highest average for any group (Anaktwvuk Pass, Alaska) was about one-half of this value. Since cesium 137 contamination of the lichens is a surface phenomenon—very little is taken up from the soil—and the normal biological time to remove half of any remaining cesium activity in the body is only about 100 days or possibly less, the annual dose should drop off in 1964–65.

Evaluation

A whole body exposure of 175 roentgens (Marshallese experience in 1954) is far in excess of an acceptable exposure. As contrasted with the surface bursts in 1954, the 1962 U.S. tests in the Pacific were bursts in the air high enough above the surface to eliminate measurable local fallout.

Only a few individuals have exceeded by small amounts the criterion of 10 roentgens in 10 years established for the Nevada Test Site.

The whole body average population 30 year exposure of 110 milliroentgens (0.11 roentgen) is about three percent of that from natural sources. The *difference* in natural background radiation levels at various localities in the United States can be much greater than all of the whole body exposure from fallout.

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*A milliroentgen is 1/1000 of a roentgen.

C. SKIN EXPOSURES

Background Information

Radioactive fallout debris emits beta particles some of which emerge from fallout material with sufficient range in air to reach from the ground to the head of an erect man. However, in human tissue the range of these beta particles is limited principally to a very small fraction of an inch so that only the skin is irradiated when fallout debris is outside the body. Further, there has been no observed skin damage except from relatively heavy fallout where the radioactive fallout material has remained in direct contact with the bare skin. Even a single layer of cotton clothing apparently greatly reduces the radiation dose from beta particles.

Approximately a 500 roentgen dose delivered by beta particles from fallout debris to the base of the outer layer of the skin tissue is required to produce erythema (reddening of the

FIGURE 4a. – Highly radioactive fallout material remained in contact with the feet causing severe skin damage – 28 days after initial contamination.

FIGURE 4b.—Same case six months later. Damage healed with normal pigmentation except for small spots marking the areas of more severe damage.

skin). A similar result from X-rays would require less radiation dose. At somewhat higher doses from beta particles emitted by fallout debris epilation (loss of hair) may occur. At still higher doses more serious skin damage may be expected with such symptoms as ulceration.

The Data

Skin damage from beta burns was first observed on some cattle grazing near the Alamogordo, New Mexico Test Site following the first nuclear detonation on July 16, 1945. Epilation was observed in patches where the fallout debris had supposedly remained in place. The hair grew back, white in color, and no other adverse effects have been observed in the cattle or their offspring.

Other "beta burns" have been observed on a few cattle in 1952, on horses in 1953, and one horse in 1955 in Nevada. All of these, as well as the Alamogordo cattle were grazing within

20 miles of ground zero where there was relatively heavy local fallout from the bursts occurring on towers. Crude estimates suggest that the external whole body exposures in these same areas would have been in excess of 75 roentgens from gamma rays.[11]

The principal example of skin damage was in the case of the Marshallese people following the heavy fallout on March 1, 1954.[4] The most damaged areas were (a) in the regions of hair on the head (oiled), (b) folds of the moist bare skin such as the neck region and inner elbow, and (c) tops of the feet where the fallout material remained in place (figs. 4a and 4b). The extent of skin damage to the most heavily exposed group may be summarized as follows.

	45 individuals	superficial lesions
	13 individuals	deep lesions
	6 individuals	no lesions
Total	64	
	35 individuals (of the 64 above)	some degree of epilation

Hair of normal color and texture has regrown and all lesions have healed without visible effects except for permanent loss of pigment in the healed areas in individuals and some scar tissue behind the ear of one man, marking the location of a previous deep lesion.

Additional cases of skin damage from fallout were observed on some Japanese fishermen aboard the Fukuryu Maru and some American service personnel on the island of Rongerik, as a result of the March 1, 1954 fallout. Also, four men in charge of handling "hot" filters from monitoring aircraft at the Pacific Testing Site in 1948 received severe beta burns on the hands. One additional case was an Air Force officer in charge of transportation of radioactive samples from the Pacific Proving Ground to the United States in 1951. A lesion developed on his forehead and right eyebrow region. The damaged area showed normal repair processes but the previously black hair of the eyebrow was replaced by white hair upon regrowth.[12]

There have been no known cases of human beta burns at or around the Nevada Test Site.

Evaluation

Serious skin damage can result if highly radioactive fallout remains in direct contact with the skin. Simple measures such as washing can be very effective in reducing this hazard—the sooner the better. Skin damage has not been observed except in those areas where the amount of fallout was high, i.e., possibly over 75 roentgens whole body dose from the gamma radiation with most of this exposure occurring in the first few days. Thus, the potential hazard of skin burns may be essentially eliminated by meeting the criteria of an acceptable whole body exposure. Of course, by evacuation from a highly contaminated area it is possible to reduce drastically whole body exposure, yet a relatively high skin dose could accumulate if the fallout materials were not removed early.

D. IODINE 131

Background Information

Approximately 0.15 million curie (a "curie" corresponds to 2.2 million million disintegrations of nuclei per minute) of iodine 131 are produced for each kiloton TNT equivalent of energy released by fission. For large yield airbursts most of the iodine 131 along with other radioactive materials will be swept into the upper atmosphere (stratosphere) and, since iodine 131 has a half-life of only eight days, a large part of its activity will decay before being deposited on the earth. On the other hand, iodine 131 that remains in the lower atmosphere, the troposphere, will be deposited relatively quickly and can enter the food chain.

Milk is the principal route of entry of iodine 131 into the human body where it is selectively deposited in the thyroid gland. The assumption is usually made that 30 percent of iodine 131 ingested by humans is deposited in the thyroid no matter what the size of this organ may be.[13] Thus, an infant's thyroid gland of about two grams weight would receive 10 times more radiation dose than the 20 gram adult's thyroid for the same amount of iodine 131 ingested. For this reason calculations of radiation doses from iodine 131 for the general population are based on those for the infant rather than the adult.

Direct measurements of iodine 131 in milk were not made around the Nevada Test Site during earlier times of testing since it was the consensus of scientists within and outside the AEC and Government at that time that the limiting factor was the potential external whole body exposure. It is now recognized that there can be situations where the iodine 131 exposure can be more limiting. An example of this was the Smallboy surface shot on July 14, 1962 at the Nevada Test Site. The detonation was large enough to produce significant quantities of iodine 131 but due to its low energy yield the activity was not swept to high altitudes to be carried away,

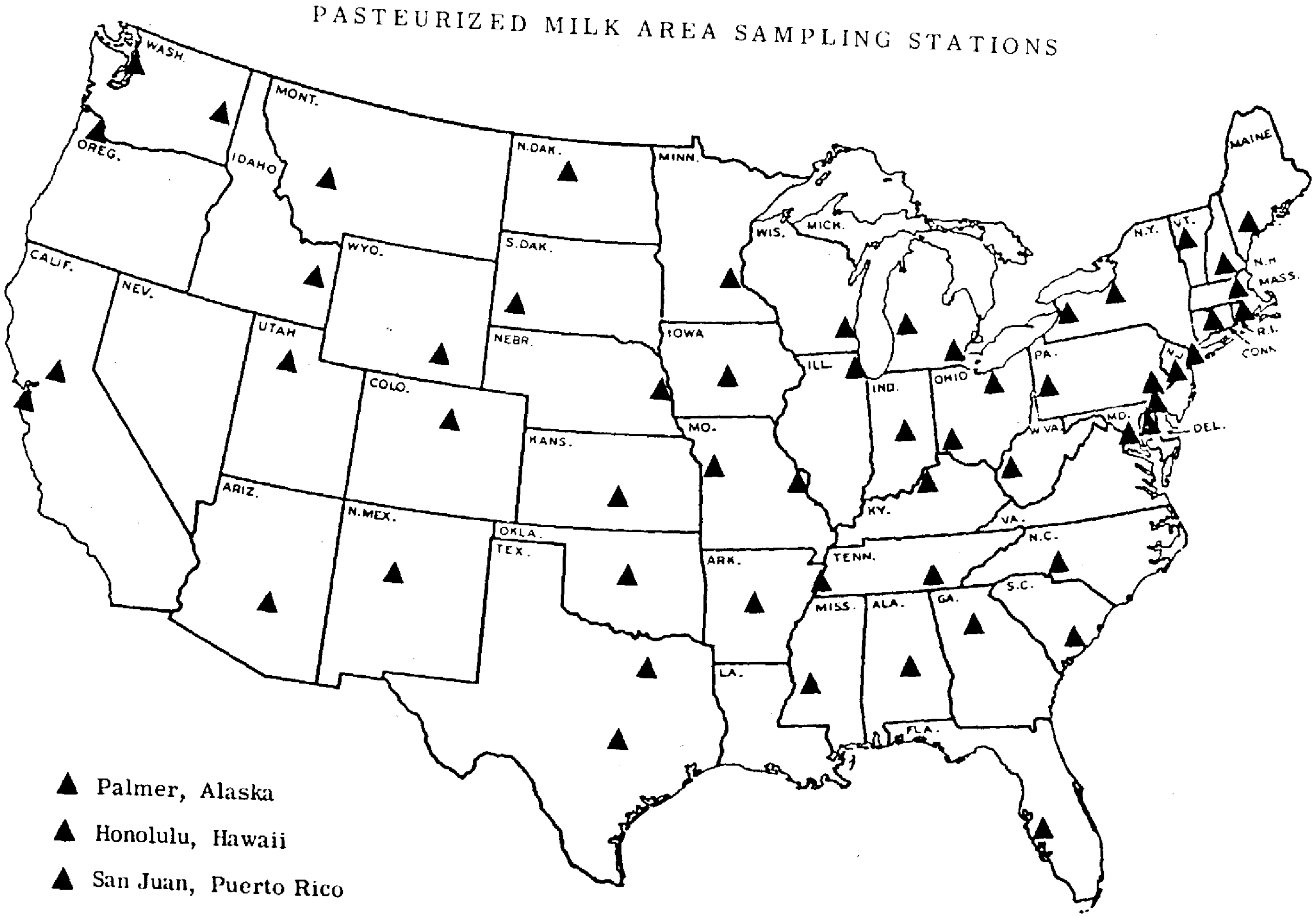


FIGURE 5.—U.S. Public Health Service National Milk Network.

diffused and diluted as had occurred for larger bursts in the atmosphere.

The Data

The highest annual average value of iodine 131 measured in milk by the Public Health Service national network (fig. 5) at any time was at St. Louis, Mo., for the period of August 1957 through July 1958[14] The calculated average dose was 1.5 roentgens to infants' thyroids based on the usual assumption of each drinking one liter of milk per day – the dose to an adult thyroid would be only about 1/10 as much. The next highest calculated total average dose was 0.69 roentgen at Palmer, Alaska (October 1961 through September 1962), and the third highest was 0.63 roentgen for Salt Lake City, Utah (September 1961 through August 1962). Because of the unevenness of the iodine deposition near the Nevada Test Site it is possible that small local areas might show values 10 times or so greater than the average for the general region. It is also probable that higher levels of iodine 131 than these existed in local areas around the Nevada Test Site during periods of heavy testing in the 1950s.

The above estimated doses to the thyroid involve some uncertainties in their determination but are based on some observed iodine 131 levels in milk samples. Theoretical calculations of thyroid doses have been attempted, based on other types of radiation monitoring such as collection of radioactive particulates in the air or measurements of radiation at three feet above the ground from deposited fallout. To date, all of these methods suffer severe uncertainties. These monitoring procedures, equipment and data are useful for the purposes for which they were intended. The difficulty is in attempting to use one type to predict another in a quantitative way.

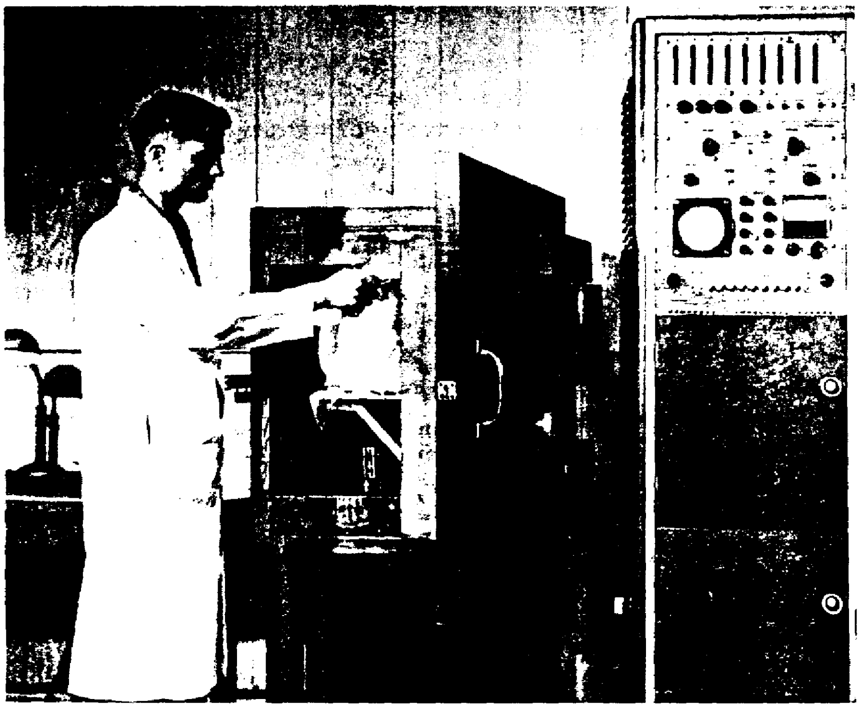
Evaluation

All of the above calculated thyroid radiation doses may be placed in perspective by reference to quoting from a National Academy of Sciences report.[15]

In describing the therapeutic use of iodine 131 in the treatment of hyperthyroidism, the report stated:

> ". . . There is no evidence at hand, except for one doubtful case in a child, that any of the treatments for hyperthyroidism has produced a thyroid cancer, although doses have ranged from a few thousand rad (roentgens) upward . . ."

There can be circumstances where levels of iodine 131 in milk can be a more controlling factor than external gamma expo-



U.S. PUBLIC HEALTH SERVICE, DIVISION OF RADIOLOGICAL HEALTH PHOTO

FIGURE 6.—Counting a sample of milk for iodine 131. The procedure is quick and simple—the milk is merely poured into a plastic container and set into the counter. In contrast, analysis of milk for strontium 90 may require weeks including radiochemical preparation of the sample.

sures that have hitherto been considered of prime interest for local fallout. However, the total potential doses that may be accrued will require the drinking of the milk over periods of weeks. Up-to-date techniques and equipment now permit a relatively easy and early surveillance of iodine 131 in the milk supply providing an opportunity for whatever action may be appropriate (Figure 6).

E. STRONTIUM 90 AND STRONTIUM 89

Background Information

Strontium 90 has a half-life of about 28 years. It is selectively deposited in the bones. Chemically it is related to calcium. This similarity has led to the use of the "strontium unit" defined as one picocurie (2.2 disintegrations per minute) of strontium 90 per gram of calcium.

Strontium 90 may become associated with foodstuffs by surface contamination of plants or by uptake of the strontium

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90 from the soil. During years of relatively heavy fallout, surface contamination has accounted for the larger part of the strontium activity in plants but in the absence of atmospheric nuclear testing the avenue of soil uptake predominates. The periods showing the highest amount of strontium 90 in the food supply have been invariably the spring and summer months following years of heaviest testing. This is because of meteorological factors and also the fact that surface contamination contributes more to the total strontium 90 activity found in plant life than does soil uptake during these periods. (Incidentally, the cesium 137 content of plant life is even more dependent on surface contamination since only very small amounts are taken up from the soil.) Areas of heavier rainfall consistently show higher levels of strontium 90.

Milk is one of the best indicators of strontium 90 in the food supply, yet at the same time it is one of the better sources of calcium. Remember it is not just the amount of strontium 90 that is important but also how much there is present in relation to calcium. In fact the total diet has had roughly 1.5 times as great a strontium 90/calcium ratio as did milk alone.[16]

Strontium 89 has the same chemical properties as strontium 90 and will follow the same metabolic paths. It is created in much larger quantities than strontium 90 but produces less of a problem since it has a shorter half-life (53 days) and emits beta particles with about one-half the energy of those from strontium 90 and its daughter product. For these reasons the strontium 89 content in milk may peak at values many times that of strontium 90 during the periods immediately following nuclear tests, yet the total radiation dose to the bone over a lifetime from strontium 89 may be only one-quarter or less than that of strontium 90.[1]

The Data

About 20 million curies of strontium 90 have been created by atmospheric nuclear tests with about 17 million curies of this being spread globally. The other 3 million curies fell quickly in areas local to the testing sites. To date, roughly 8–9 million curies of strontium 90 have been deposited globally, leaving a calculated 6 million curies in the region of the atmosphere below 100,000 feet (based on measurements using aircraft and balloons)[17] with some additional amounts above this level. The discrepancy in total numbers is due in part to radiological decay of strontium 90 but more because of uncertainties in the estimates themselves.

As expected, the peak value of "strontium units" in milk was passed in June of 1963 (32 "strontium units" as a national average).[18] In the absence of atmospheric tests these levels are expected to continue to decline generally except for small transitory rises during the next few spring seasons. The annual (1963) national average for those areas of the United States showing the highest values was 26 "strontium units" in milk. This is less than the 32 "strontium units" predicted and should foretell less in the bones than predicted.[1] Incidentally, the amount of strontium 90 in the milk produced around the Nevada Test Site is among the lowest in the country.

In general, past predictions of levels of strontium 90 in bones have been too high. This is due in part to the selection of data in the upper ranges to avoid underestimations of radiation exposure. Even so, it is remarkable that the observed amounts of strontium 90 in bones have been within about a factor of two of the predicted amounts considering the fact that such predictions require the application of many scientific disciplines—nuclear physics, meteorology, chemistry, plant and animal physiology, etc.—often to new situations.

That segment of the U.S. population whose bones will receive the highest radiation dose are children born in 1963 in regions of heavier rainfall. The total radiation exposure to these children—from internally deposited as well as external radionuclides—has been predicted to be about 465 milliroentgens (0.465 roentgen) accumulated over a 70-year period.[1]

Evaluation

The predicted average 70-year radiation dose to the bones of the age group receiving the highest exposure from all past tests—about 465 milliroentgens (0.465 roentgen) from all radioactive materials within and outside the body—is about five percent of the bone dose received during the same 70-year period from natural background sources.

F. CARBON 14

Background Information

Carbon 14 is produced naturally by interaction of cosmic rays with the nitrogen in the atmosphere. Although its radioactive half-life is long—5760 years—the process of natural production had been going on for such a great time that the rate of production and rate of decay were in equilibrium, i.e., just as much is formed each year as decays away, until nuclear test detonations were initiated. There is a constant exchange of carbon 14 atoms between the atmosphere and the surface of the earth on the one hand, and the deep ocean on the other, with the latter constituting a reservoir holding about 96 percent of the atoms.

Nuclear detonations can also produce carbon 14 by interaction of the neutrons, produced at the time of the explosion, with nitrogen of the atmosphere. Approximately 400 megatons of total yield fired in the air (surface bursts "lose" about one-half of the neutrons into the ground) will produce a sufficient amount of carbon 14 to equal the amount normally present in that part of the earth's biosphere that determines radiation exposure to man. However, half of this newly-added carbon 14 "disappears" into the deep ocean within about 33 years.[19] One-half of that remaining in the atmosphere likewise "disappears" in the following 33 years, until only a few percent remains.

Radioactive isotopes act chemically similar to their stable counterparts so that not only is stable carbon but also carbon 14 found in all living cells. Thus, although carbon 14 emits a beta particle of very low energy that travels a very short distance it nevertheless irradiates essentially the whole body at a rate of approximately one milliroentgen (0.001 roentgen) per year. This is the natural background rate for carbon 14.

The Data

Since nuclear weapons testing started 511 million tons total energy yield have been released. Considering the conditions of firing (surface versus air bursts) about the same amount of carbon 14 was produced from all past tests as is normally present in that part of the earth's biosphere that determines radiation exposure to man. Assuming that most of the carbon 14 produced by the detonation will "disappear" into the deep ocean with a half-time of 33 years, the estimated whole body exposure for 70 years is 37 milliroentgens (0.037 roentgen).[1]

After this 70-year period the dose rate from bomb produced carbon 14 will be about one-quarter of that at the start, i.e., about one-quarter of one milliroentgen (0.00025 roentgen) per year. Thereafter, the activity will persist for thousands of years but at ever decreasing levels.

Evaluation

The radiation exposure from carbon 14 may account for roughly one-third of the total radiation dose from fallout over the next 70 years. Because of its long radiological half-life, it will persist at low levels of activity for thousands of years. However, even before the 70-year period is completed the dose rate from carbon 14 will be so low as to be non-measurable. This does not mean that the radiation is not "there" but it will be minuscule compared to natural background levels or even to normal variations of background radiation.

G. WATER AND AIR

Background Information

Water

Contamination of water supplies does not constitute a major source of intake of radioactive fallout debris. In the case of surface water supplies there is a very large dilution factor.

In the case of underground nuclear detonations the fission products are restricted largely to the immediate vicinity of the detonation due principally to two factors. Firstly, for underground shots to date approximately 90 percent of the fission products have been fixed in a glassy type of material formed by the detonation. Secondly, ion exchange between such key fission products as strontium 90 and cesium 137, and the soil resulted in almost all of the remaining activity being adsorbed within a matter of perhaps tens to hundreds of feet away from the source.[20] In addition to fission products, tritium may be formed in varying amounts. This radioisotope probably is not greatly influenced by the two factors mentioned and must depend upon the dilution factor for reduction of the concentration in the water—at least for underground detonations. For above ground or cratering shots, the tritium largely escapes into the atmosphere where very large dilutions occur. Theoretical calculations suggest it may be possible for relatively high concentrations of tritium to be present in the amount of water immediately surrounding ground zero of some underground nuclear detonations.[21]

Essential to predicting potential contamination of ground water is the determination of the water movement. The most satisfactory method of obtaining the necessary data for this prediction is by drilling operations. Although these are expensive operations they are carried on extensively at the testing sites.

Air

As long as the fallout material from atmospheric tests remains in the air some may be inhaled and irradiate the lungs. This radiation dose to the lungs normally is less than external whole body exposure occurring after the fallout has been deposited on the ground. Also in general, inhalation is only a minor contributor to the intake of fallout debris into the body—ingestion is the much more important route.

The whole body will also receive some exposure from the penetrating gamma rays while the fallout material is in the air, but this dose will usually be small compared to the exposure that follows after the debris is deposited on the ground. However, this ratio of doses may not hold for events where most of the radioactivity that escapes beyond the test site is in the form of gases or finely suspended particles that are confined to a relatively shallow layer of air near the surface.

Measurements of total fallout activity in air (called gross beta counts) provide only a crude alerting system. It is not a reliable procedure for predicting the amount of fallout to be deposited nor the amount of iodine 131 in milk.[22] Because of the transitory nature of the fallout debris remaining in the air (and sometimes because of the particular choice of units used in expressing its concentration) what may sound like an alarmingly large amount may, in fact, result in only minor radiation doses.

The Data

Water

The highest measured fallout activity in water was at Upper Pahranagat Lake, Nev., in 1955 amounting to 0.14 millionth of a curie per liter.[23] Since this was a total gross beta count it is difficult to give a precise estimate of the potential radiation dose. A crude analysis suggests that if this water had been stored and used as a sole supply for 70 years the total dose might be about one roentgen to the bones and one-quarter roentgen each to the thyroid and lower large intestine.

No radioactive fission products nor induced activities including tritium from underground tests have been found in underground water supplies at places of human consumption.

Air

The highest concentration of radioactive debris in the air in a populated area off-site (except for the Marshallese experience where measurements were made only after the passage of the cloud) was about 1.3 millionth of a curie per cubic meter averaged over the 24 hours the activity was present.[24] This happened at St. George, Utah, on May 19, 1953. The estimated radiation dose to the lungs from inhaled fallout debris was less than 0.2 roentgen.[25] The external whole body exposure from the fallout while it was still in the air was roughly estimated to be 0.025 roentgen – only about 1/100 of the whole body exposure that occurred after deposition of the fallout.

Evaluation

The concentrations of fission products or tritium in the water supplies have not constituted major sources of radiation exposure to man. There is a large dilution factor when surface water supplies are contaminated, and the fission products from underground nuclear detonations largely become fixed at and near the site of the explosion. Whereas, theoretical calculations suggest that concentrations of tritium in the water may be above acceptable limits for some underground nuclear detonations,[19] this refers only to the water immediately around ground zero. Some dilution is to be expected if it moves off-site and, more importantly, the criterion of "acceptable limits" is based on the assumption that all of the water drunk throughout a lifetime will contain the same concentration of tritium as set by the limits. The quantity of water initially contaminated to these limits by an underground nuclear explosion is relatively small and would not constitute the sole supply for a lifetime. Further, tritium decays with a half-life of about 12 years.

Much less radioactive fallout debris enters the body by inhalation than by ingestion. While the debris is in the air outside the body the radiation exposure is much less than after the material has been deposited on the ground with the possible exception of certain situations noted above.

SECTION II.

OTHER ASPECTS

A. BLAST — DIRECT AND REFLECTED

Background Information

Direct blast waves that are potentially damaging are confined to the immediate testing site areas. Under certain meteorological conditions, however, blast waves may be refracted (bent) from an upper atmospheric level back to the earth and thus create higher air pressures than would be expected at those distances.

One layer in which this may happen is between 25,000 and 50,000 feet altitude where winds may cause a focusing effect at some 20–50 miles from the point of detonation. In turn, the blast wave may be repeatedly reflected from the ground and bent back from the atmosphere creating a series of regular spaced points of focus at the earth's surface with intervening "silent" spaces. Such an effect has resulted in minor structural damage, such as breaking of windows, 75 to 100 miles from the point of detonation at the Nevada Test Site [26] (fig. 7).

A similar effect is obtained when blast waves are bent from a layer of relatively warm air, called the ozonosphere, at a height of 20 to 30 miles. The point of first return to the earth in this case is 70 to 150 miles from the burst.

There may be a return of sound waves from an altitude above 60 miles (ionosphere). Most of this blast energy is absorbed, however, resulting in no recorded structural damage. In some cases audible sharp cracks and pops have been heard.

Procedures and equipment have now been developed to predict with greater accuracy the magnitude and direction of these refracted blast waves.

The Data

Although the blast wave decreases in energy with each succeeding refraction back to the earth's surface, there has been breakage of windows on a second "strike" at 285 miles from only a 17 thousand ton (TNT equivalent) nuclear explosion.[26] (Altogether about $50,000 has been paid for structural damage claims from all tests at the Nevada Test Site.) There have

FIGURE 7.–A downtown Las Vegas window, showing how the glass was sucked out by the rarefaction wave, rather than pushed in by the compression wave resulting from the November 1, 1951, nuclear test at the Nevada Test Site.

been no significant structural damages from refracted blast waves since good predictive methods have been developed.

There has been no known case of direct injury to man or animals from the refracted blast waves.

Evaluation

The predictive procedures developed resulted in greatly minimizing off-site damage from blast effects. In fact, there have been only incidents of single windows being damaged since 1953. Two occurred in 1955 and a third in 1957.

B. THERMAL RADIATION — FLASH AND HEATING EFFECTS

Background Information

Levels of thermal radiation that can produce skin burns are limited to the immediate testing site areas. Effects on the eyes, however, may extend for much greater distances.

These effects may be either permanent damage to part of the eye or a temporary flash "blindness." The latter is only a discomforting effect but can be potentially hazardous in the case of automobile drivers and aircraft pilots. This is one of the reasons why certain areas of highways have been closed for specified periods of time around the Nevada Test Site and also why the same precautions have been taken for the air lanes around the Nevada and Pacific testing sites.

Perhaps surprisingly, the amount of heat (calories) received per unit area on the rear portion of the eyeball (retina) does not decrease with increasing distance from the point of burst—except for the absorption (attenuation) effect in the atmosphere. While the expected decrease in energy per unit area does occur outside the eye (the inverse square law), the image formed on the retina correspondingly decreases in size in the same proportion. The result is that the thermal dose, in calories per unit area, remains constant but it covers a smaller area on the retina. This reduction in image size on the retina with increasing distance from the burst continues until it reaches approximately 0.00018 inch (7 microns) in diameter which is generally taken as about the limit for the maximum focusing effect of the human eye. Of course a dilation of the pupil of the eye, such as at nighttime, will permit more light to enter and, although the retinal image size does not change, it can be relatively more hazardous. Also, it is assumed that any light gathering devices such as binoculars also would increase the hazard.

Any damage to the retina probably would not be detected by an eye examination if it were less than 50 microns in diameter. Actual functional impairment of vision probably would not be noted if the lesions were mild and less than 50 microns in diameter on the fovea—the most sensitive portion of the retina.

There may be less injury to the retina of the eye if a given total amount of thermal energy is received at a slower rate, i.e., there is more opportunity for the adjacent cells in the retina to conduct away some of the heat. High yield detonations in the lower atmosphere exhibit a slower rate of delivery than low yields (say, a million tons versus 20 thousand tons).

At very high altitudes, say above 150 miles, only about 1/100,000 of the total yield from a megaton detonation appears promptly as energy in the visible light region because of the thin atmosphere.[27] Principally for this reason, such high altitude detonations do not present a serious hazard for eye damage. Detonations occurring at lesser altitudes encounter more atmosphere, where there are greater opportunities for interaction of the bomb debris with the air, resulting in a greater fraction of the total energy appearing as prompt visible light.

Detonations below about 60 miles can produce sufficient energy in the visible light region to be a potential eye hazard if they occur above the horizon and are viewed directly. Experience at Hiroshima and Nagasaki suggest that permanent eye injury would be expected only if one were looking directly at the fireball. This applies only to the instant of burst. If the detonation occurs below the horizon, the instant of high thermal energy release is past before the fireball rises into view. Under these conditions human reflexes of blinking or turning away should further insure safety.

The Data

There have been no recorded permanent eye injuries to persons off-site, although a few individuals near the Nevada Test Site have complained of temporary eye impairment. The burst from a 1.4 million tons detonation that took place over Johnston Island in the Pacific on July 9, 1962 at an altitude of about 250 miles was viewed directly under nighttime conditions by thousands in the Hawaiian Islands without any reported eye injury.

Six military personnel participating in nuclear weapons tests have received eye injury—only one of which resulted in a severe visual handicap.[28, 29] The latter individual "sneaked" a view over his left shoulder at the time of the detonation resulting in a reduction of 20/20 vision to 20/100 in his left eye. It did not improve with time. His right eye apparently was shielded by his nose and retained its 20/20 visual acuity.[28] (Values such as 20/100 represent the ability of the eye to read standard letters and characters at 20 feet that a normal eye could read at 100 feet. 20/400 is generally interpreted as legal blindness.)

Two military personnel at Johnston Island participating in the high altitude tests in 1962 also received eye injury. Immediately after the exposure, the visual acuity of both eyes of one man dropped to 20/400 for the area of primary retinal injury and 20/100 for adjacent areas of the retina. This man's visual acuity recovered to 20/30 in one eye and 20/40 in the other about one month later, and to 20/25 in both eyes about a year afterwards in the area of primary retinal damage. The

FIGURE 8.—Special high density goggles are worn by observers on-site at the Nevada Test Site. Note man at right of center without goggles, but who has turned away from the direction of burst. This procedure is equally safe providing there is no reflecting surface directly in view.

other man's visual acuity followed a similar pattern starting at 20/400 in both eyes in the area of retinal damage and 20/60 in the adjacent areas. These recovered to 20/50 and 20/80 in a month, and at one year later to 20/40 on one eye and 20/60 in the other in the areas of primary retinal damage.[30]

Experimental rabbits were exposed under nighttime conditions to the high altitude shot on August 1, 1958—a detonation in the megaton range at an altitude of about 48 miles. Lesions with diameters of about 500 microns were observed out to 345 miles—the farthest distance at which rabbits were exposed.

Evaluation

Nuclear detonations in the yield range tested offer no serious hazards to the eye when they are at very high altitudes, say above 150 miles, or below the horizon at the instant of burst. Detonations in the lower atmosphere should not be viewed directly without the aid of special high density goggles (Figure 8). Past precautionary procedures of closing highways and air lanes near the testing sites at the times of bursts have added to the safety in respect to potential eye damage. The procedures also were useful in preventing a driver or pilot being startled while in motion.

C. WEATHER

Background Information

Interest in the possible effects of nuclear detonations on the weather fall into two classes; one, direct effects because of the energy released, and two, triggering effects. The latter effects might be (a) a catalytic effect from the particles thrown into the atmosphere (something akin to cloud seeding with silver iodide crystals), (b) a change in the electrical conductivity of the air since radioactive debris contains charged particles, and (c) a reduction of solar energy received on earth owing to the quantity of dust thrown into the atmosphere.

The Data

The conclusions of many studies and experiments of these possible effects are best presented in reference:[31]

> 1. ". . . The energy of even a thermonuclear explosion is small when compared to most large-scale weather processes. Moreover, it is known that much of this energy is expended in ways that cannot directly affect the atmosphere. Even the fraction of the energy which is directly added to the atmosphere is added in a rather inefficient manner from the standpoint of affecting the weather. Meteorologists and others acquainted with the problem are readily willing to dismiss the possibility that the energy released by the explosions can have any important direct effect on the weather processes . . ."
> 2. ". . . The debris which has been thrown up into the atmosphere by past detonations was found to be ineffective as a cloud-seeding agent . . ."
> 3. ". . . The amount of ionization produced by the radioactive material is insignificant in affecting general atmospheric conditions . . ."
> 4. ". . . Dust thrown into the air by past volcano eruptions decreased the direct solar radiation received at the ground by as much as 10–20 percent. The contamination of the atmosphere by past nuclear tests has not produced any measurable decrease in the amount of direct sunlight received at the earth's surface. There is a possibility that a series of explosions designed for the maximum efficiency in throwing debris into the upper atmosphere might significantly affect the radiation received at the ground . . ."

The volume of material ejected by Krakatoa volcanic eruption in 1883 was approximately 13 cubic miles with an estimated one-third of the volume being spread worldwide.[32] This resulted in a diminution of the amount of sunlight received on the ground.[33]

As a crude comparison, the 10.4 million tons TNT equivalent nuclear detonation on October 31, 1952 on the island of Elugelab in the Pacific left a crater of about one mile in diameter and 170 feet deep at its apex. Assuming conservatively that the crater was a right angle cone and that all of the debris was thrown into the atmosphere, i.e., none of the depression was caused by compression, it is estimated that about 15,000 million tons TNT equivalent of surface detonations would be required to eject an amount of dust into the atmosphere equivalent of Krakatoa.

Following large nuclear detonations in the Pacific minor and temporary weather changes have been observed, such as local cloud formation sometimes with local precipitation, where the moisture conditions in the atmosphere are most favorable for this effect.

Evaluation

The most inclusive evaluative statements made are found in references 31 and 2.

> ". . . No statistically significant changes in the weather during the first ten years of the atomic age have been found, yet careful physical analysis of the effects of nuclear explosions on the atmosphere must be made if we are to obtain a definite evaluation of this problem. Although it is not possible to prove that nuclear explosions have or have not influenced the weather, it is believed that such an effect is unlikely . . ." (1956).
>
> ". . . although there has been much speculation about the influence of atomic testing on weather, there still appears to be no additional evidence suggesting a cause and effect relationship . . ." (1960).

D. GROUND MOTIONS—EARTHQUAKES

Background Information

A wide variety of factors determine both the ground motions and structural responses from nuclear detonations, i.e., energy yields of the detonations, distance from ground zero, depth of the shot and depth of measurement, and the nature of the ground (hard rock, etc.). "Competent" rock such as granite couples and transmits more energy into seismic ground waves than does alluvium—a noncohesive sedimentary deposit. Although ground waves will be more rapidly absorbed in alluvium, it is possible for waves to travel great distances along the surface with relatively large amplitudes (amount of motion) if the alluvium is very thick. However, these surface waves die out rapidly with the depth into the ground. Because of the above factors, it is necessary to analyze each situation in predicting possible ground motions and structural responses.

One way to express the effects of ground motion is in units of "g." This refers to the acceleration that a freely falling body experiences on earth, i.e., 32 feet per second change in velocity for each second that the acceleration occurs. As a "rule of thumb"—the threshold of ground motion that may be perceptible to humans is one-thousandth (1/1000) of a "g." Ground motions can be accentuated at higher places such as tall buildings.

As another "rule of thumb," one-tenth of a "g" is frequently accepted as the criterion for threshold of property damage. However, this is based on damage from earthquakes and present data show that seismic waves generated by nuclear detonations and chemical high explosives result in less damaging effects than would be predicted for the same peak acceleration from an earthquake. Part of this difference may lie in the fact that ground motions from earthquakes persist for a longer period of time for each shock. Also, there are repeated shocks in most cases. Thus, structures are subjected to more damaging effects because of the number of shocks and greater duration of each shock than would be the case for the same peak acceleration experienced as a result of ground motion from an underground nuclear explosion.

Since nuclear detonations produce ground motions, it has been speculated that they may "trigger" a natural earthquake. It is not possible to have a natural earthquake, however, without prior storage of strain energy—a process that occurs over a period of years. It would be necessary to conduct an explosion several miles deep in an earthquake susceptible area to be near a zone where the stress might be great enough for an incipient quake to be triggered.[34]

The response of structures to earthquakes has been the subject of study for many years and satisfactory procedures have been developed for design of structures to withstand the effects of earthquakes. However, in these cases the interest is in significant structural damage, rather than plaster cracking or other minor effects. In the case of underground nuclear explosions the site is selected with safety in mind so that structures outside the test area will not ordinarily be subjected to ground motions of more than small amplitude. The possibility that light damage may result, therefore, must be considered.

The Data

The maximum range at which seismic waves from the largest nuclear detonations to date at the Nevada Test Site are known to have been perceived by persons without benefit of instruments has been about 100 miles. These few persons were situated under conditions favorable to the amplification of the ground motions. No structural damage from ground motion has been experienced beyond about six miles from the site of the nuclear detonations.

Evaluation

Records of ground motion are now available for many underground nuclear explosions. Analyses of data and application of geophysical principles are resulting in a steady improvement in methods of prediction of ground motions for planned events.

Since ground motions from underground nuclear explosions are different in some respects from those from an earthquake and there is a need to predict marginal damage to structures for such explosions a new approach is required. The analytical procedures for structural response generally are valid and can be applied. Additional direct test information is required and is being acquired by the AEC. Until more data are developed, conservative estimates of the effects may be made by comparison with damage which might be expected from the same amplitude of ground motion in an earthquake.

SECTION III.

GENERAL EVALUATIONS

The decision to conduct nuclear weapons tests for the defense of our country was made at the highest level of our Government. The Atomic Energy Commission was charged with the responsibility for carrying out the program. The AEC sought and followed the best advice both from within and outside the Government in the conduct of new and potentially hazardous operations. The record, as summarized above, must speak for itself as to potential risks incurred to the public in the fulfillment of a mission essential to national security.

Of all the health aspects of nuclear weapons testing, that of radiation exposure has received the greatest attention. If, as the data and their evaluation given above indicate, there has been a relatively low degree of risk associated with past atmospheric tests (except for the fallout on the Marshallese and the Japanese fishermen), then why has there been so much concern expressed? There are probably several reasons.

First, whereas the potential radiation exposures are only a very small fraction of those received from natural background sources, they are, of course, *additional* amounts.

Second, in the absence of positive proof otherwise the prudent assumption is accepted that for every small increment of radiation exposure there is a corresponding increment of biological effect ("linear" concept)—rather than the "threshold" concept where a certain total radiation dose must be received before irreparable damage occurs. Based on this and other assumptions, admissible theoretical calculations can be made as to the potential number of genetic mutations, of cases of leukemia, etc. that could result from fallout. This linear concept leads axiomatically to the situation of there being no sharp dividing line below which there is complete safety and above which there is a serious hazard. Radiation protection guides, therefore, must be derived on some additional basis, as noted next.

Third, there has been some misinterpretation of the radiation protection guides. The use of the linear concept leaves little choice for deriving radiation protection guides, i.e.—there must be a balancing of the "benefits" anticipated from any atomic energy program, whether it be for normal peacetime operations or national defense, against the "risks" (radiation exposure). Obviously, this is an exceedingly complex and, in part, subjective process.

In spite of these difficulties this balancing of benefits from normal peacetime operations against risks has been performed by the Federal Radiation Council (FRC) resulting in their recommending radiation protection guides for this purpose.[13, 35] In a letter of August 17, 1962 to the Joint Committee on Atomic Energy, Congress of the United States, the FRC clarified further their published Guides:

> ". . . the Guides were originally developed for application as guidelines for the protection of radiation workers and the general public against exposures which might result during 'normal peacetime operations' in connection with the industrial use of ionizing radiation . . . the term 'normal peacetime operations' referred specifically to the peaceful applications of nuclear technology where the primary control is placed on the design and use of the source. Since numerical values in the Guides were designed for the regulation of a continuing industry, they were of necessity set so low that the upper limit of Range II can be considered to fall well within levels of exposure acceptable for a lifetime. Furthermore, to provide the maximum margin of safety, the upper limits of Range II were related to the lowest possible level at which it was believed that nuclear industrial technology could be developed . . ."

Guides developed primarily for use by industry in restricting its releases of radioactive effluents to the general environment outside their controlled areas are, of course, very materially lower than those that might constitute a serious health hazard.

A fourth reason why concern has been expressed about health risks from fallout may lie in the area of causal relationships, i.e., the identifying or associating of nuclear tests with nuclear war. There may have been established in the minds of some that nuclear weapons testing and nuclear war go hand-in-hand, i.e., the first axiomatically leads to the second. A discussion of causal relationships is beyond the scope of this booklet, yet one point must be made.

As a matter of technical fact, nuclear weapons of proven performance would not have been possible without the testing of nuclear devices and the verifying of nuclear concepts that were incorporated into their design. Whatever protection we enjoy from our nuclear arsenal results from a stockpile of test-proven nuclear weapons, not a stockpile of drawing board sketches.

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APPENDIX

SAFETY PROCEDURES AT THE NUCLEAR TESTING SITES

NEVADA TEST SITE

General

The safety programs and procedures described below were in use during atmospheric tests at the Nevada Test Site. Since the signing of the Limited Test Ban Treaty essentially all of these programs remain in effect, but generally at a reduced level, thus providing for a continuous monitoring of persons and the environment for documentary purposes, and assurance of a nucleus of well trained personnel (fig. 9).

The health and safety of persons was the major consideration in the original selection of the Nevada Test Site and this continues to be of paramount importance during the conduct of nuclear tests. An exhaustive search was made before the Nevada site was selected as the most suitable one. It originally contained 600 square miles (later expanded to about 1,290 square miles) adjacent to the U.S. Air Force Gunnery Range of 4,000 square miles. For purposes of general safety, as well as security, the Test Site was and continues to be closed to the public. Safety of personnel was and is further assured by aerial and surface surveys made prior to each detonation to determine that no one had wandered into the area.

Beyond these controlled areas are wide expanses of sparsely populated land, providing optimim conditions for maintenance of safety. Although the area is quite sparsely populated the individual resident has been given full consideration. Radiation monitors have been present during times of testing and there have been occasions when residents have been relocated for a day or so to insure fully their safety. Persons relocated have received financial remuneration for such movements. There have also been occasions when persons have been asked to remain indoors for a few hours to reduce the radiation dose, although the out-of-door exposure would have been far from hazardous.

Before each and every nuclear detonation at the Nevada Test Site, an Advisory Panel of experts weighed carefully all of the factors that insured safety. On the panel were repre-

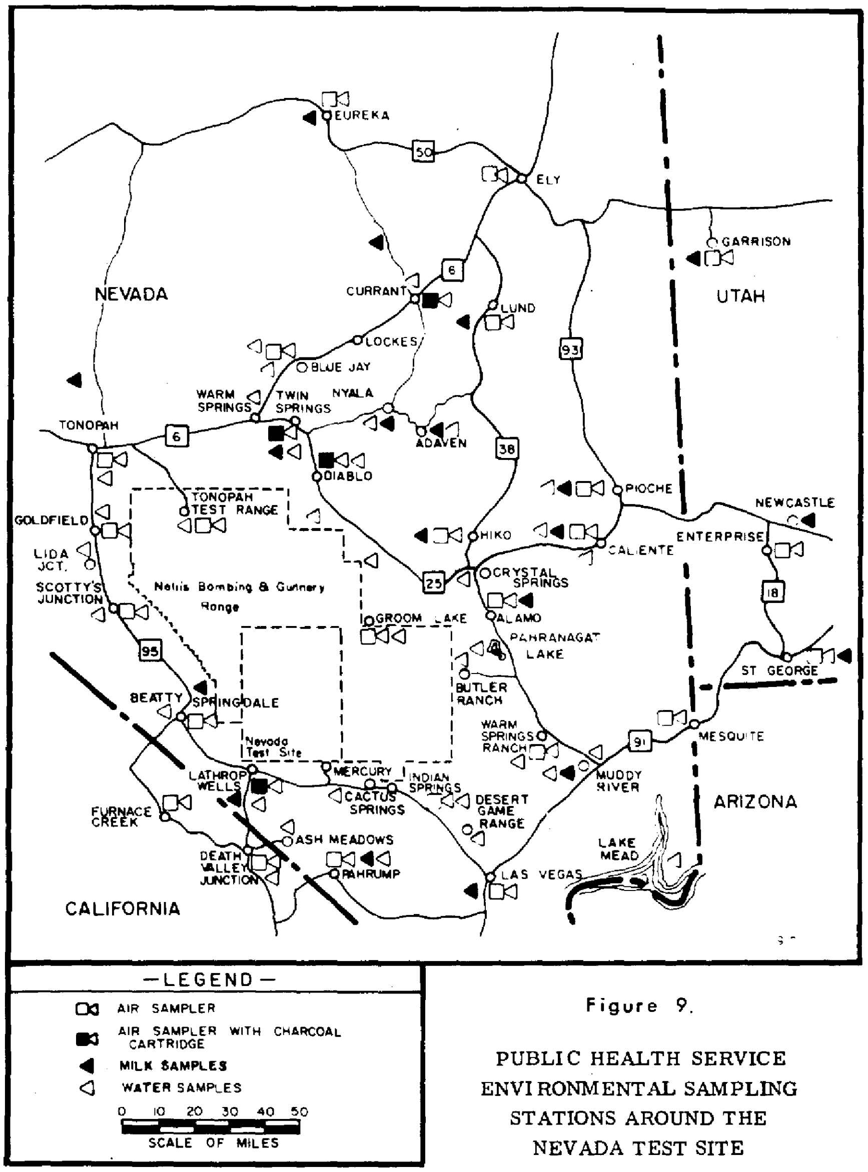


Figure 9.

PUBLIC HEALTH SERVICE ENVIRONMENTAL SAMPLING STATIONS AROUND THE NEVADA TEST SITE

sentatives from the fields of public health, medicine, meteorology, fallout phenomenology, blast and thermal effects, etc. As a result of these deliberations more than 200 delays in firing have been made at a cost of millions of dollars, to insure safety. The Advisory Panel continues to function for underground tests.

The principal cause for the delays was the requirements for proper weather conditions to insure minimum fallout in populated areas. Meteorologists predicted downwind trajectories, precipitation and other factors which could affect levels of fallout. The data from the weather stations were currently available almost up to the exact time of the shot. A detonation could be cancelled at any time up to a few seconds before shot time. A more complete description of the meteorological program is given below.

To insure safety to aircraft, both from the initial flash of light and any radioactivity in the air mass moving off-site from atmospheric tests, a representative of the Federal Aviation Agency was made an integral part of the Test Organization. He prepared flight advisory plans based on the type of event and on the predicted meterological conditions. The plan delineated flight patterns and areas and recommended alternate routes, if required, by commercial and private aircraft. Frequently the FAA closed specific air lanes and rerouted aircraft for specified periods.

Blast effects were minimized by predicting blast wave intensities based on the wind and temperature profile expected at shot time. Since long distance blast pressure propagation is strongly dependent on wind profile structure, calculations were made for many directions and distances from the test site where possible window damage might have occurred. In order to improve blast calculation techniques, a network of especially sensitive microbarographs was operated at as many as 17 off-site locations to record actual shot-produced pressures in Nevada, California and Utah. It was rarely necessary to recommend a delay in firing time solely because of predicted blast effects since meterological conditions unfavorable for fallout usually were also unfavorable for blast.

Full off-site radiological monitoring coverage was and is provided by the U.S. Public Health Service under a Memorandum of Agreement with the U.S. Atomic Energy Commission. There were and are extensive monitoring programs, including mobile monitoring teams, film badges, air samplers, automatic gamma recorders, collections of milk, vegetation, soil, etc. A more complete description of these programs is given below. All of the key data obtained from these monitoring programs were and are reported in the open literature such as the Atomic Energy Commission's Semiannual (now annual) reports to Congress and the U.S. Public Health Service's monthly publication, *Radiological Health Data*. An extensive public information program by the U.S. Public Health Service continues around the Nevada Test Site (fig. 10).

U.S. PUBLIC HEALTH SERVICE, DIVISION OF RADIOLOGICAL HEALTH PHOTO

FIGURE 10.—Public Health Service representative conducting a meeting in one of the local homes in Las Vegas, as a part of an extensive educational program around the Nevada Test Site.

Weather Predictions

The Weather Bureau Research Station was started in 1956 to study intensively the meterology of the Nevada Test Site. In late 1957 the station became responsible for providing meterological support for nuclear weapons tests. Prior to these dates this function was performed by the Air Weather Service of the U.S. Air Force. The Weather Bureau station at the Nevada Test Site received all of the atmospheric sounding information taken every six hours by the stations shown on the map (fig. 11), and most of the hourly and six-hourly weather information produced in the entire United States, Canada, Mexico and eastern Pacific Ocean. In addition, there were and are some 26 wind, 20 temperature, and 18 precipitation measuring stations located on the Test Site. Ten of the wind and three of the temperature stations that reflect major terrain effects at and near the Nevada Test Site provided telemetered information for use just prior to and immediately following each nuclear detonation.

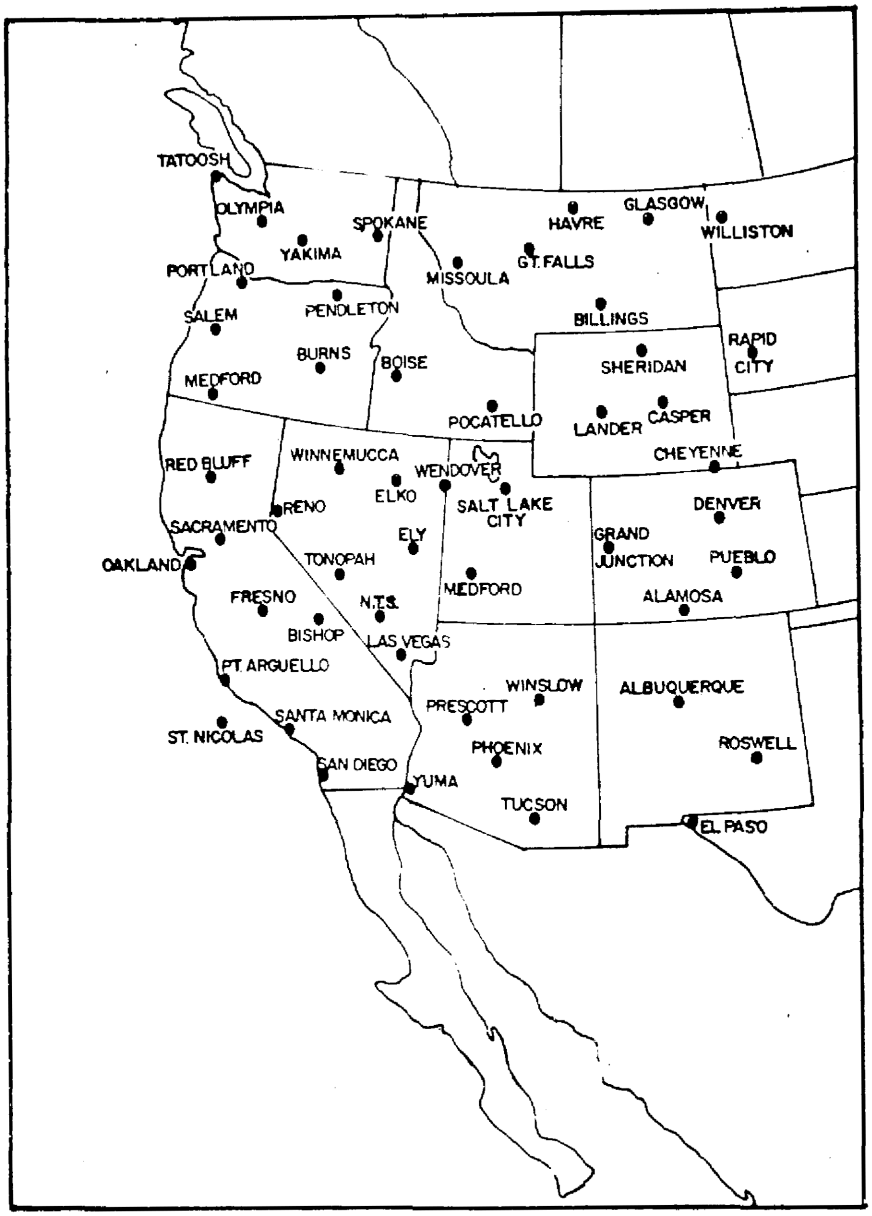


FIGURE 11.—U.S. Weather Bureau stations furnish information every six hours for forecasting purposes.

The Mercury Weather Station made a daily study of the weather conditions over the Nevada Test Site and environs, using all available local information and reevaluating analyses furnished by means of facsimile from the National Meterological Center (NMC) at Suitland, Md. The latter Center proc-

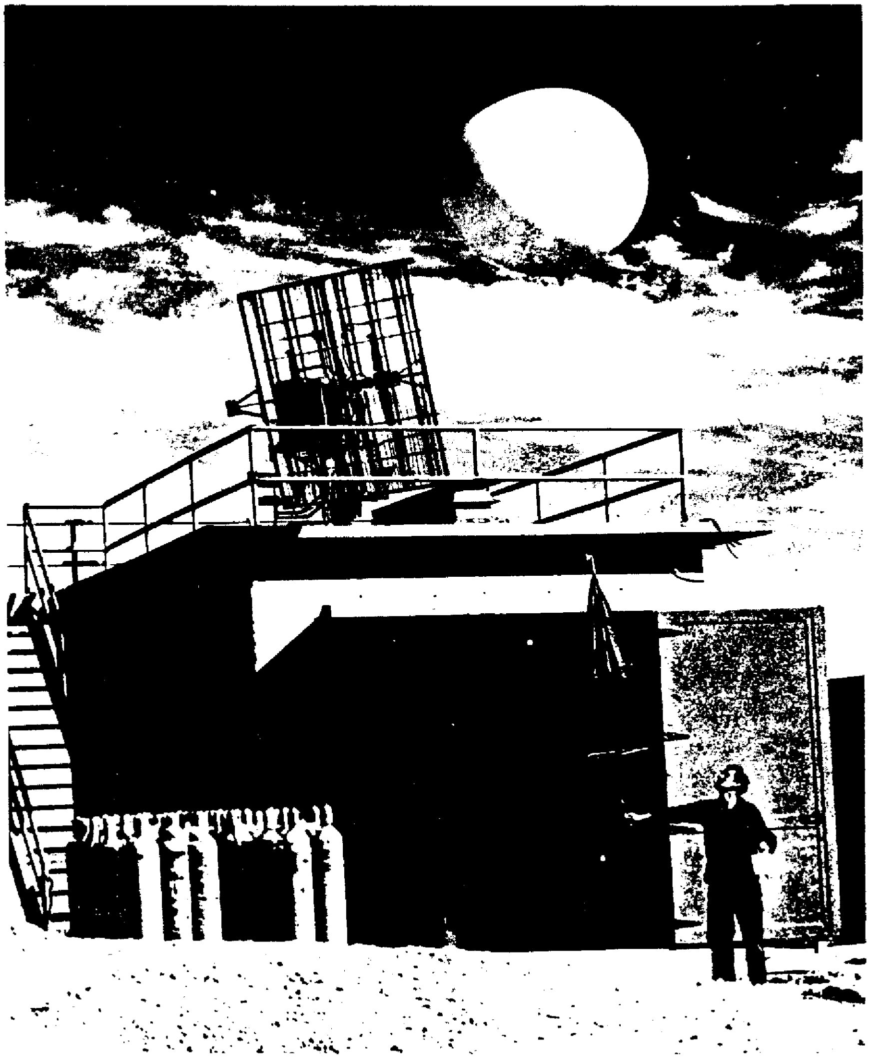


FIGURE 12.—The Weather Station at the Nevada Test Site sends radar-observer balloons to the upper atmosphere to check on temperatures, dew points, humidity and wind velocities. The radar tracking instrument on top of the station charts wind velocities and directions.

essed most northern hemisphere data, much of it electronically, and used the fastest and most modern techniques in producing forecast charts of the large scale features of the atmospheric circulation. The Mercury station, having more local information and the benefit of numerous studies of local meterological conditions, adjusted the NMC information to make forecasts having the highest possible accuracy for NTS.

On the day prior to each nuclear detonation, a formal detailed briefing was given to the Scientific Director, the Test Manager, and his Advisory Panel covering all foreseeable ways in which weather might influence the success and safety of the test. All such briefings included wind speeds and direction predictions to at least the maximum cloud height obtainable, expected changes in wind during the day, thermal stability, clouds, precipitation, trajectories of aerosols, the effect of wind and thermal structure on the diffusion and deposition of effluent materials, and the maximum radiation dosages that could conceivably result on and off the Test Site. Changes, if any, from these predictions were presented at subsequent briefings just prior to arming each device. In fact one of the major factors in arriving at good predictions was the series of "wind runs" usually at one-half hour intervals up to zero time (fig. 12).

Most of the programs remain in effect as a further assurance of safety in the event of the release of any radioactivity from underground tests.

Radiological Surveillance

Routine programs were and are conducted continuously within a radius of approximately 300 miles from the Nevada Test Site by the U.S. Public Health Service.

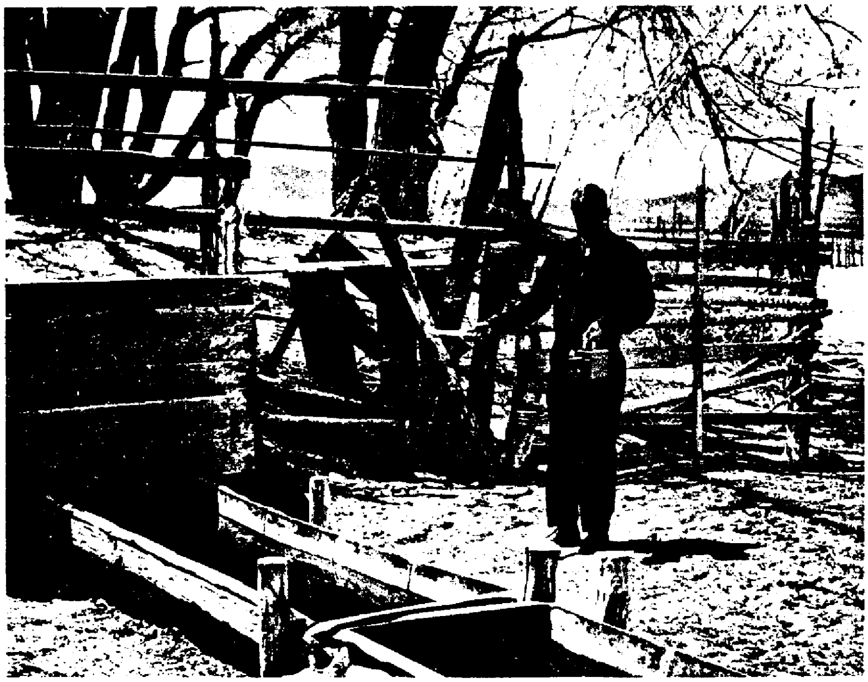
Aircraft Monitoring

Since 1962 the U.S. Public Health Service has owned and operated two aircraft for cloud sampling. Prior to this date, this function was accomplished by the U.S. Air Force. Each aircraft carried equipment to collect airborne activity both particulate and gaseous. Both planes carried equipment for continuously monitoring the gamma radiation. Additional U.S. Air Force planes equipped for cloud sampling and tracking were available and were on call. Arrangements were made for the use of another special aircraft for radiological monitoring surveying at H+24 hours.

The capabilities of aircraft monitoring continue to be maintained.

Mobile Ground Monitoring

Mobile ground monitoring teams were deployed in the downwind sector prior to each test to supplement the routine surveillance which was a part of the continuous surveillance program. The downwind sector was determined by information obtained from the U.S. Weather Bureau personnel assigned to the NTS. These monitoring teams consisted of two men. Each team was equipped with beta-gamma survey



U.S. PUBLIC HEALTH SERVICE, DIVISION OF RADIOLOGICAL HEALTH PHOTO

FIGURE 13.—Monitoring for external gamma radiation near the Nevada Test Site by U.S. Public Health Service personnel.

instruments (fig. 13), chamber survey instruments, fallout trays and additional air samplers and recorders. Each vehicle was equipped with two-way voice radio communication. The number of teams used for each event was determined in advance by the predicted radiological situation, however five to ten teams was the usual number deployed. Up to 20 teams could be organized within a short time, but were not normally maintained on a standby basis.

Mobile ground monitoring teams are still maintained on a standby basis and used when needed.

Air Sampling

There were and are 30 permanent air sampling stations in operation 24 hours per day in the area surrounding the NTS at distances up to 180 miles.

The air samplers used are high volume units, drawing air through an 8″ x 10″ glass fiber filter (fig. 14). When deemed desirable, a secondary activated charcoal cartridge is added for the collection of gaseous fission products. Flow rates are approximately 50 cubic feet per minute (c.f.m.) for the glass fiber filter alone and 25 c.f.m. with the charcoal cartridge added.

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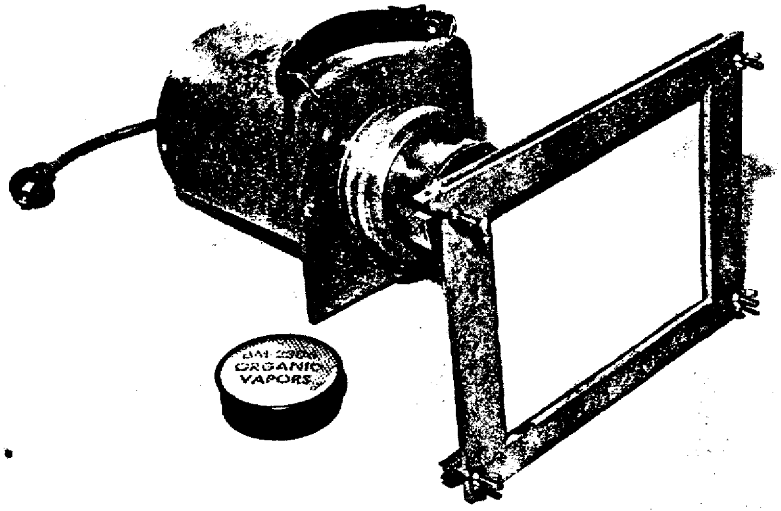

FIGURE 14.—High volume air sampler. The large glass fiber filter is for collection of particulates. Behind the filter is placed an activated charcoal cartridge to collect gases such as radioiodines.

Glass fiber filters are counted for gross beta activity in the proportional region.

All charcoal cartridges, and any glass fiber filters with gross beta activity significantly above background levels are assayed with a 400 channel gamma scintillation spectrometer, using a steel shield for a 4" x 4" NaI (T1) crystal with a Cs^{137} peak resolution of eight percent for identification of specific gamma-emitting isotopes.

Film Badging

Film badges were distributed to hundreds of locations around the Test Site and to as many as 1,600 persons during certain operations. Presently there are about 50 locations with some 200 persons wearing film badges. Film badges were and are collected and processed monthly. In the event that radioactivity was found in the area by the mobile monitoring teams, film badges were collected from these locations and from people living in the area; new film badges were distributed. Additional stations and people were included if the situation required more extensive monitoring.

U.S. PUBLIC HEALTH SERVICE, DIVISION OF RADIOLOGICAL HEALTH PHOTO

FIGURE 15.—Collection of water sample near the Nevada Test Site by U.S. Public Health Service personnel.

Milk Sampling

Milk samples were and are collected routinely one time per month within the 300 mile radius of the NTS, from approximately 25 sources, including all dairies and some additional ranches having one milk cow. In the event that radioactivity was found in any area additional samples were collected often on a daily basis.

Water Samples

Water samples were and are in general collected monthly from approximately 30 sources (fig. 15). There were no known surface supplies for human use in the off-site area except for Lake Mead.

Research

In support of the operational procedures described above to assure safety to the public, there were and are extensive basic and applied research studies conducted in such fields as meterology, hydrology, and ground motion. These were and are accomplished by (a) cooperation with other Government agencies including the U.S. Weather Bureau, U.S. Public Health Service, U.S. Geological Survey, U.S. Bureau of Mines and U.S.

Coast and Geodetic Survey, (b) contracts with consulting organizations such as Roland F. Beers, Inc., Alexandria, Va., Hazleton-Nuclear Science Corporation, Palo Alto, Calif., and Holmes & Narver, Inc., Los Angeles, Calif., and (c) individual consultants.

The total annual expenditure for the operational and research studies directed toward safety at the Nevada Test Site currently is over $8 million.

In addition, there were and are numerous programs carried on as part of the laboratories' scientific effort that have a bearing on safety and contribute greatly to the basic understandings. One of the earliest and most valuable were those environmental studies conducted by the Department of Biophysics and Nuclear Medicine, University of California Medical School, Los Angeles, Calif. Also, in May 1963 a new Biology Division at the Lawrence Radiation Laboratory at Livermore, Calif., was formed with one of its prime missions to investigate problems dealing directly and indirectly with radioactive fallout, especially radioiodine.

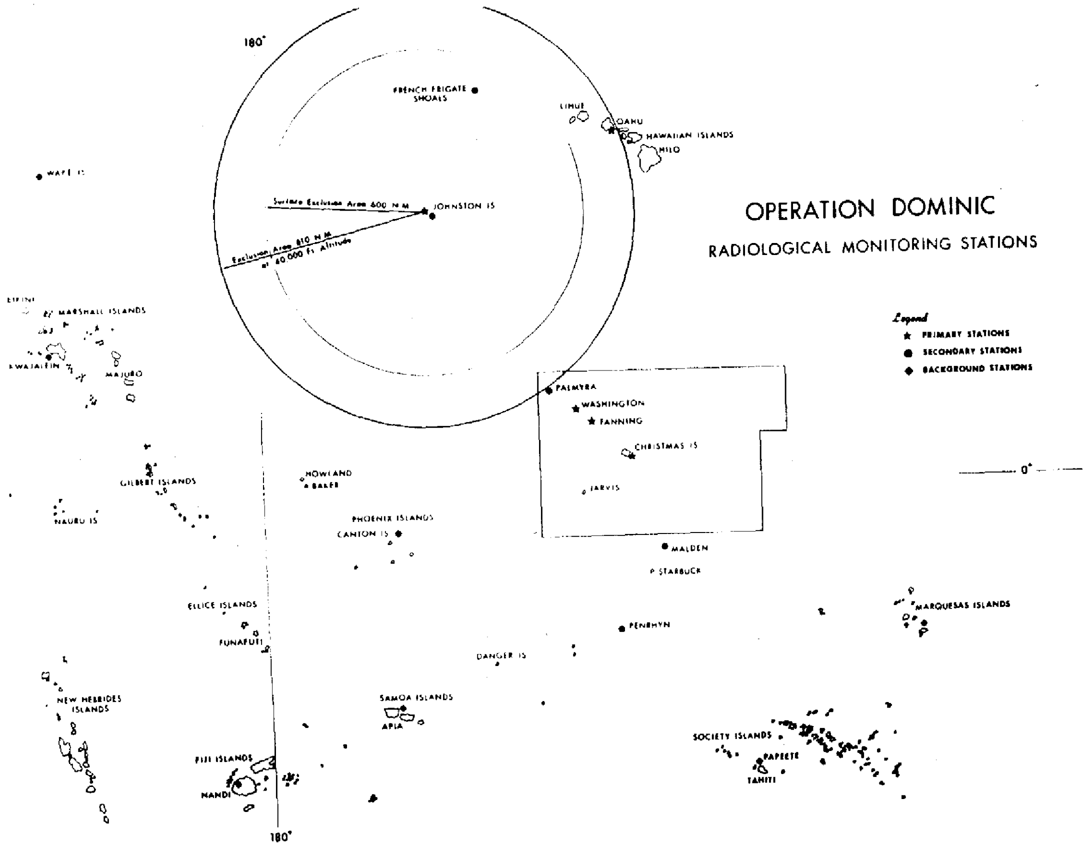
OPERATION DOMINIC
RADIOLOGICAL MONITORING STATIONS
Legend
★ PRIMARY STATIONS
● SECONDARY STATIONS
◆ BACKGROUND STATIONS
180°
FRENCH FRIGATE SHOALS
LIHUE
OAHU
HAWAIIAN ISLANDS
HILO
WAKE IS
Surface Exclusion Area 600 N.M.
JOHNSTON IS
Exclusion Area 810 N.M. at 40,000 Ft Altitude
ENIWETOK
MARSHALL ISLANDS
KWAJALEIN
MAJURO
GILBERT ISLANDS
NAURU IS
HOWLAND
BAKER
PHOENIX ISLANDS
CANTON IS
ELLICE ISLANDS
FUNAFUTI
NEW HEBRIDES ISLANDS
FIJI ISLANDS
NANDI
SAMOA ISLANDS
APIA
DANGER IS
PALMYRA
WASHINGTON
FANNING
CHRISTMAS IS
JARVIS
MALDEN
STARBUCK
PENRHYN
MARQUESAS ISLANDS
SOCIETY ISLANDS
PAPEETE
TAHITI
0°
180°

FIGURE 16.

APPENDIX

SAFETY PROCEDURES AT THE NUCLEAR TESTING SITES

PACIFIC TEST SITES

General

United States atmospheric nuclear tests were held in the Pacific at Bikini (1946, 1954, 1956 and 1958), Eniwetok (1948, 1951, 1952, 1954, 1956 and 1958), Johnston Island (1958 and 1962) and Christmas Island (1962). These remote sites were selected after extensive search for possible areas where the tests could be conducted safely.

To conduct atmospheric nuclear weapons tests in the Pacific, Joint Task Forces have been organized consisting of designated personnel from U.S. Military Services and AEC. A Commander for each Joint Task Force was chosen from one of the three Military Services with a Deputy from each of the other two. The technical programs have been under a civilian Scientific Deputy.

In each series an exclusion area was declared around the test islands for the purpose of warning air traffic and ships (fig. 16). Notification of locations of these areas and times that the restrictions were in effect were made by issuance of Notices to Airmen through the Federal Aviation Agency and Notices to Mariners through the Commander-in-Chief of the Central Pacific Fleet. The Department of Defense, State Department and other agencies of the Executive Branch of the Government were notified so that shipping authorities and air traffic control authorities could be alerted.

Since there have been some changes in details over the years of the organizations concerned with safety within the Joint Task Forces, the following description applies to Joint Task Force 8 that conducted the 1962 Pacific tests.

Weather predictions were conducted by the Task Force Weather Central composed of Navy and Air Force meterologists. To assist in analyzing the weather data and to predict other results such as fallout, blast and thermal effects, a Hazards Evaluation Unit was formed to advise the Joint Task Force Commander and his Scientific Deputy.

Radiological safety activities on-site were conducted by a special unit of Joint Task Force 8 and off-site surveillance programs by the U.S. Public Health Service.

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Altogether about 80 personnel were utilized in activities devoted to safety.

Radiological Surveillance

Radiological safety (Rad-Safe) was a separate Task Unit within the Joint Task Force organization. Rad-Safe responsibilities included procuring, storing, and issuing Rad-Safe supplies and equipment, instrument maintenance, issuance and processing of film badges, maintenance of personnel radiation exposure records, supervision of monitoring, decontamination, waste disposal activities, procurement and distribution of high density goggles, and other activities as indicated by the potential hazards of the situation. The Rad-Safe Branch contained an Off-Site Surveillance Section. Personnel from this section participated in monitoring at off-site populated islands in the vicinity of the test area and periodically collected water and food samples.

Aircraft Monitoring

Aircraft were used to monitor the cloud of airborne radioactivity during early times after detonation and to track the cloud periodically over a period of two or three days.

Environmental Safety

During Operation Dominic (1962) there were 35 nuclear detonations above the Pacific Ocean near Christmas and Johnston Islands. The explosive yields of these devices ranged from low kiloton into the megaton range in TNT equivalent. The height of burst for each detonation was sufficient to negate local radioactive fallout. The devices were delivered to the point of detonation by either manned aircraft or by surface-to-air missiles. In addition to the atmospheric tests, there was one underwater test of a low yield nuclear device detonated in the Eastern Pacific Ocean several hundred miles from the closest land area. Essentially all the radioactive fission products produced by this test were deposited in the ocean and were soon dispersed and diluted to concentrations which were of no significant biological hazard to man or marine life.

All nuclear events at Christmas Island were detonations of devices released from manned aircraft. These bursts occurred over water and were planned for execution under favorable atmospheric conditions to minimize the likelihood of contamination of land surfaces. In addition, following each event, ground and aerial monitors surveyed the island to determine whether any radioactive rain-out occurred.

A Hazards Evaluation Unit composed of scientific personnel of contractor laboratories (Lawrence Radiation Laboratory, Los Alamos Scientific Laboratory, Sandia Corporation) and representatives of the U.S. Weather Bureau was organized to advise the Commander of the Joint Task Force and the Scientific Deputy. Pre-shot computations were made for each detonation. These computations included 12 and 24 hour trajectory forecasts based on winds from the surface to 40,000 feet. A specified radiation exclusion area was then declared to include any possible local fallout. Daily soundings were made to 100,000 feet giving added information that was helpful in correlating observed cloud stabilization and movement with predicted shot-time trajectories. Where applicable, other weapons phenomena were considered such as blast pressures, and possible eye injuries from the prompt thermal radiation.

Cloud tracking aircraft made and maintained contact for several hours with the radioactive cloud following each event conducted in the lower atmosphere. Timely information on cloud movement, top and base altitudes were obtained for use of advisory reports regarding opening of commercial air lanes through or near the announced danger area. There was no evidence that any commercial aircraft encountered any of these radioactive clouds.

Off-Site Monitoring

The off-site monitoring program during Operation Dominic was under the cognizance of the U.S. Public Health Service, USPHS personnel being assigned to JTF–8 during the operational phase. A radiological surveillance of a network of 19 monitoring stations was maintained on populated islands within a 2,000 mile radius of Christmas Island. Air samples were collected on populated islands out to about 1,000 miles from the test zone. Samples of soil, vegetation, fruits, water and marine life were collected on the populated islands of the area before testing began and repeated sampling was made after the testing period to determine whether changes in the level of radioactivity had occurred in the area.

The 19 sampling stations were divided into (1) primary stations, (2) secondary stations, and (3) background stations. The primary stations (Christmas, Fanning and Washington) were manned by USPHS officers with equipment and sampling techniques to document all forms of environmental radioactivity. The secondary stations (Canton, Malden, Penrhyn/Tongareva, Palmyra, Midway, Johnston Island and French Frigate Shoals) were outside the danger area and were designed to document air concentration and external radiation background. These stations were operated with the assistance of Task Force Project Groups and Weather Groups. Background stations on Tu-

tuila, Rarotonga, Wake Island, Kwajalein Atoll, Tongatabu and Viti Levu were operated by Task Force Project Groups or Weather Groups and on Nuku Hiva and Tahiti by French personnel. The purpose of the background stations was to document external radiation background and changes in background levels if they occurred.

A USPHS rad-chem laboratory was established in Honolulu, Hawaii to support the off-site rad-safe program. Facilities, equipment and personnel were available for radiochemical analysis of air, precipitation, water, milk, food and soil. The facility remains in operation as a part of a continuing program of monitoring several of the Hawaiian Islands.

Bioenvironmental Monitoring

The bioenvironmental program for Operation Dominic was under AEC contract with the University of Washington, Seattle, Wash. A final report of their data is found in "Radionuclide Content of Foodstuffs Collected at Christmas Island and at Other Islands of the Central Pacific During Operation Dominic, 1962," UWFL-87, by Ralph Palumbo.

During the period April 7 to July 29, 1962, collections of foodstuffs, marine life included, were made from eight off-site islands and Christmas Island to ascertain the radionuclide content of the samples collected. In addition to samples collected by this group, USPHS off-site monitors furnished samples from areas not covered by the University of Washington scientists. Approximately 8,000 samples were collected during the time which covered pre-testing, testing and post-testing periods. Part of these samples were scanned promptly for radioactive content, however, a majority of the samples were returned to the University of Washington for complete analysis.

GLOSSARY*

BACKGROUND RADIATION: Nuclear (or ionizing) radiations arising from within the body and from the surroundings to which individuals are always exposed. The main sources of the natural background radiation are potassium 40 in the body, potassium 40 and thorium, uranium, and their decay products (including radium) present in rocks, and cosmic rays.

BETA PARTICLE: A charged particle of very small mass emitted spontaneously from the nuclei of certain radioactive elements. Most (if not all) of the direct fission products emit (negative) beta particles. Physically, the beta particle is identical with an electron moving at high velocity.

BIOLOGICAL HALF-TIME: The time required for the amount of a specified element which has entered the body (or a particular organ) to be decreased to half of its initial value as a result of natural, biological elimination processes.

DOSE: A (total or accumulated) quantity of ionizing (or nuclear) radiation. The term dose is often used in the sense of the *exposure dose*, expressed in roentgens, which is a measure of the total amount of ionization that the quantity of radiation could produce in air. This should be distinguished from the *absorbed dose*, given in reps or rads, which represents the energy absorbed from the radiation per gram of specified body tissue. Further, the *biological dose*, in rems, is a measure of the biological effectiveness of the radiation exposure.

DOSE RATE: As a general rule, the amount of ionizing (or nuclear) radiation to which an individual would be exposed or which he would receive per unit of time.

EXPOSURE, EXTERNAL: Exposure to radiation that is delivered from a source outside of the body.

EXPOSURE, INTERNAL: Exposure to radiation delivered from a source inside the body. Strontium 90 lodged in the bones is an example of internal exposure.

EXPOSURE, WHOLE BODY: Exposure that involves the whole body rather than a specific organ.

FALLOUT: The process or phenomenon of the fallback to the earth's surface of particles contaminated with radioactive material from the radioactive cloud. The term is also applied in a collective sense to the contaminated particulate matter itself. The *early* (or *local*) *fallout* is defined, somewhat arbitrarily, as those particles which reach the earth within 24 hours after a nuclear explosion. The *delayed* (or *world-wide*) *fallout* consists of the smaller particles which ascend into the upper troposphere and into the stratosphere and are carried by winds to all parts of the earth. The delayed fallout is brought to earth, mainly by rain and snow, over extended periods ranging from months to years.

FISSION PRODUCTS: A general term for the complex mixture of substances produced as a result of nuclear fission. A distinction should be made between these and the *direct fission products* or *fission fragments* which are formed

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* Based principally on The Effects of Nuclear Weapons. Glasstone, S. (editor). Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. April 1962.

by the actual splitting of the heavy-element nuclei. Something like 80 different fission fragments result from roughly 40 different modes of fission of a given nuclear species, i.e., uranium 235 or plutonium 239. The fission fragments, being radioactive, immediately begin to decay, forming additional (daughter) products, with the result that the complex mixture of fission products so formed contains about 200 different isotopes of 36 elements.

FOOD CHAIN: The sequence of events in which nutrients are transferred from the soil to plants to animals to man. The collection of these various stages is referred to generally as the biosphere.

FREE AIR OVERPRESSURE (OR FREE FIELD OVERPRESSURE): The unreflected pressure, in excess of the ambient atmospheric pressure, created in the air by the blast wave from an explosion.

FUSION: The process whereby the nuclei of light elements, especially those of the isotopes of hydrogen, namely, deuterium and tritium, combine to form the nucleus of a heavier element with the release of substantial amounts of energy.

GAMMA RAYS (OR RADIATIONS): Electromagnetic radiations of high energy originating in atomic nuclei and accompanying many nuclear reactions, e.g., fission, radioactivity, and neutron capture. Physically, gamma rays are identical with X-rays of high energy, the only essential difference being that the X-rays do not originate from atomic nuclei, but are produced in other ways, e.g., by slowing down (fast) electrons of high energy.

GROUND ZERO: The point on the surface of land or water vertically below or above the center of a burst of a nuclear (or atomic) weapon; frequently abbreviated to GZ.

HALF-LIFE: The time required for the activity of a given radioactive species to decrease to half of its initial value due to radioactive decay. The half-life is a characteristic property of each radioactive species and is independent of its amount or condition. The *effective half-life* of a given isotope is the time in which the quantity in the body will decrease to half as a result of both radioactive decay and biological elimination.

INDUCED RADIOACTIVITY: Radioactivity produced in certain materials as a result of nuclear reactions, particularly the capture of neutrons, which are accompanied by the formation of unstable (radioactive) nuclei. The activity induced by neutrons from a nuclear (or atomic) explosion in materials containing the elements sodium, manganese, silicon, or aluminum may be significant.

INVERSE SQUARE LAW: The law which states that when radiation (thermal or nuclear) from a point source is emitted uniformly in all directions, the amount received per unit area at any given distance from the source, assuming no absorption, is inversely proportional to the square of that distance.

ISOTOPES: Forms of the same element having identical chemical properties but differing in their atomic masses (due to different numbers of neutrons in their respective nuclei) and in their nuclear properties, e.g., radioactivity, fission, etc.

KILOTON ENERGY: The energy of a nuclear (or atomic) explosion which is equivalent to that produced by the explosion of 1 kiloton (i.e. 1,000 tons) of TNT.

MEGATON ENERGY: The energy of a nuclear (or atomic) explosion which is equivalent to 1 million tons (or 1,000 kilotons) of TNT.

METABOLISM: The process in which the body breaks down foods into usable materials that are taken into the cells and manufactured into the living tissues of the body.

MICROCURIE: A one-millionth part of a curie.

MILLIREM: A one-thousandth part of a rem.

MILLIROENTGEN: A one-thousandth part of a roentgen.

OVERPRESSURE: The transient pressure, usually expressed in pounds per square inch, exceeding the ambient pressure, manifested in the shock (or blast) wave from an explosion.

PICOCURIE: One millionth of a millionth of a curie.

RAD: A unit of absorbed dose of radiation; it represents the absorption of 100 ergs of nuclear (or ionizing) radiation per gram of the absorbing material or tissue.

RBE (OR RELATIVE BIOLOGICAL EFFECTIVENESS): The ratio of the number of rads of gamma (or X-) radiation of a certain energy which will produce a specified biological effect to the number of rads of another radiation required to produce the same effect is the RBE of this latter radiation.

REM: A unit of biological dose of radiation; the name is derived from the initial letters of the term "roentgen equivalent man (or mammal)." The number of rems of radiation is equal to the number of rads absorbed multiplied by the RBE of the given radiation (for a specified effect).

REP: A unit of absorbed dose of radiation now being replaced by the rad; the name rep is derived from the initial letters of the term "roentgen equivalent physical." Basically, the rep was intended to express the amount of energy absorbed per gram of soft tissue as a result of exposure to 1 roentgen of gamma (or X-) radiation.

RESIDENCE HALF-TIME: As applied to delayed fallout, it is the time required for the amount of weapon debris deposited in a particular part of the atmosphere, e.g., stratosphere or troposphere, to decrease to half of its initial value.

ROENTGEN: A unit of exposure dose of gamma (or X-) radiation. It is defined precisely as the quantity of gamma (or X-) radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit quantity of electricity of either sign.

STRATOSPHERE: A relatively stable layer of the atmosphere between the tropopause and a height of about 30 miles in which the temperature changes very little (in polar and temperate zones) or increases (in the tropics) with increasing altitudes. In the stratosphere clouds of water never form and there is practically no convection.

TNT EQUIVALENT: A measure of the energy released in the detonation of a nuclear (or atomic) weapon, or in the explosion of a given quantity of fissionable material, expressed in terms of the weight of TNT which would release the same amount of energy when exploded. The TNT equivalent is usually stated in kilotons or megatons.

TRITIUM: A radioactive isotope of hydrogen, having a mass of 3 units; it is produced in nuclear reactors by the action of neutrons on lithium nuclei.

TROPOPAUSE: The imaginary boundary layer dividing the stratosphere from the lower part of the atmosphere, the troposphere. The tropopause normally occurs at an altitude of about 25,000 to 45,000 feet in polar and temperate zones, and at 55,000 feet in the tropics.

TROPOSPHERE: The region of the atmosphere immediately above the earth's surface and up to the tropopause in which the temperature falls fairly regularly with increasing altitude, clouds form, convection is active, and mixing is continuous and more or less complete.

WEAPON DEBRIS: The highly radioactive material, consisting of fission products, various products of neutron capture, and uranium and plutonium that have escaped fission, remaining after the explosion.

X-RAYS: Electromagnetic radiations of high energy having wave lengths shorter than those in the ultraviolet region.

YIELD (OR ENERGY YIELD): The total effective energy released in a nuclear (or atomic) explosion. It is usually expressed in terms of the equivalent tonnage of TNT required to produce the same energy release in an explosion. The total energy yield is manifested as nuclear radiation, thermal radiation, and shock (and blast) energy, the actual distribution being dependent upon the medium in which the explosion occurs (primarily) and also upon the type of weapon and the time after detonation.

ACKNOWLEDGEMENTS

The author is deeply grateful to the following for their expert advice and assistance. Any shortcomings in this pamphlet, however, are solely the responsibility of the author. Appreciation is expressed especially to Dr. Roy D. Maxwell for his generous assistance and to Mrs. Edith J. Meyers for her typing of the manuscript.

Atomic Energy Commission
Mr. Robert E. Allen
Dr. H. David Bruner
Dr. Charles L. Dunham
Mr. Richard Hamburger
Dr. John H. Harley
Mr. Donald W. Hendricks
Mr. Joshua Z. Holland
Mr. Alfred W. Klement, Jr.
Dr. Roy D. Maxwell
Mr. Tommy F. McCraw
Colonel MacPherson Morgan
Captain Benjamin R. Petrie, USN
Mr. James E. Reeves
Mr. Otto H. Roehlk
Dr. Donald M. Ross
Mr. Carl G. Welty, Jr.
Mr. Arthur J. Whitman

Roland F. Beers, Inc.
Mr. James M. Klaasse
Mr. Lawrence B. Luhrs
Mr. Sherwood B. Smith

U.S. Weather Bureau
Mr. Phillip W. Allen
Mr. Frank D. Cluff
Mr. Gilbert J. Ferber
Mr. Robert J. List
Dr. Lester L. Machta
Mr. Kosta Telegadas

Brookhaven National Laboratory
Dr. Robert A. Conard

Sandia Corporation
Mr. Hugh W. Church
Dr. Thomas B. Cook, Jr.
Mr. William Kingsley
Mr. Jack W. Reed

Los Alamos Scientific Laboratory
Dr. Alvin C. Graves
Dr. Herman Hoerlin

Medical College of Virginia
Dr. William T. Ham, Jr.

U.S. Public Health Service
Mr. John R. McBride
Mr. Oliver R. Placak
Mr. Morgan Seal

Joint Task Force–8
Major Arthur L. Knipp, Jr.

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U.S. GOVERNMENT PRINTING OFFICE : 1964 OL—745-413

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