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Feb 64

Attached is a redraft of a proposed pamphlet Health Aspects of Nuclear Weapons Testing.

I would appreciate very much your comments by February 28, 1964.

We have been unable as yet to assemble an appropriate set of graphics. If you have any, or know of someone who has, please let me know. Due credits will be given.

Gordon M. Dunning
Deputy Director
Division of Operational Safety

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HEALTH ASPECTS OF NUCLEAR WEAPONS TESTING

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 with the health aspects of nuclear weapons testing in the atmosphere. Nothing new is contained herein and much has been omitted for brevity. It is hoped, however, that this pamphlet may in some small way assist in further enlightenment of a complex subject.

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U. S. Atomic Energy Commission
Washington, D. C.

CONTENTS

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 USSR tests accounting for about 70 percent of the total.[1] Included in this total energy release is about 193 million tons of 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 fallout. The remaining Sections deal 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?

(Graphics No. 1 (See list at end of document)

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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 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 than those from natural background radiations. The radiation from natural sources and those 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 gamps in our knowledge, it is abundantly clear that radiation is by far the best understood environmental hazard . . .". [2]

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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 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" of exposure the following table (Table 1) is included.

(Table 1.)

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, forming a large number of unstable radionuclides. Other induced radioactive products result from inert materials capturing neutrons that are released during either the fission or fusion process. (Fusion is the process wherein hydrogen nuclei are joined together.) 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 20).

Some of these nuclides 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. Larger particles and those in the lower levels of the cloud fall nearby. (Graphics No. 2) 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 almost no effect on the pattern of distribution.

Roughly, a nuclear detonation of one-half a 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 (called the troposphere). They are deposited on the earth's surface at such a rate that one-half of the amount remaining in the atmosphere at any one time falls in 3-4 weeks (called tropospheric residence half-time). As the nuclear detonations increase in energy yield more and more of the fission products are swept higher and higher into the stratosphere - the zone above the troposphere. The residence half-time now becomes more like one-half a year for injection into the lower stratosphere in the polar regions and one year 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. (Graphics No.4)

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. (Graphics 3)

For surface bursts of high (million ton range) yield from 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 - create little, if any, local fallout.

Table 2 tabulates some of the key data on estimated nuclear energy yields from all past nuclear weapons tests. The total energy release is of interest in estimating the amount of carbon-14 produced. It is assumed that the carbon-14 is distributed more or less uniformly around the world. Of the total energy release of 511 million tons equivalent of TNT about 70 percent resulted from USSR tests.

Table 2 also shows that tons of the fission products from 161 million tons was scattered globally. Approximately two-thirds of this amount originated from USSR tests. It will, however, account for about three-quarters of the long-term fallout in the United States because of meteorological factors - 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 iodine-131 in the local environment.

3.

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At the time of a nuclear detonation something like 200 different radioactive substances are formed by fission and additional ones 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, most of the radionuclides have short radioactive half-lives and soon decay away or have other characteristics such as being highly insoluble so that they are of little health consequence. 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 doses are 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 similified by considering first cesium-137 and then lumping all of the remainder radionuclides together.

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, of course, most of them will remain and thus will 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 lesser 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 27 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. Yet cesium-137 does have a short enough 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 may be greater than that received from cesium-137 within 30 years.

The main entry of fallout into the body is by way of ingestion; inhalation contributes only a minor fraction. Most, but certainly not all, of the radionuclides are quite insoluble and pass through the gastrointestinal tract with only a minor irradiation of the stomach and intestines. The principal radionuclides that are absorbed into the body after ingestion of radioactive contaminated foods are iodine-131, strontium-90, strontium-89, cesium-137 and carbon-14.

The Data -

The highest whole body exposures ever experienced from nuclear weapons tests 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]. From 1956-1962 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. There were, of course, noticeable effects immediately after the irradiation such as nausea and itching of the skin (see section on Skin Exposure below (Section I C page 12).

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 determination.

It was reported by the Japanese that some fishermen aboard a vessel near by 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 from hepatitis. (Hepititis is a condition not directly attributable to radiation.)

The next highest whole body exposures occurred near the Nevada Test Site. The highest estimated exposure to any individual was 13-1/2 roentgens and the next highest 10-1/2 roentgens. The highest estimated exposure to any community was about 6 roentgens. There were about 30 persons who received exposures between 6 and 10-1/2 roentgens. All of the above radiation doses are accumulated doses since the Nevada Test Site opened in 1951[8].

Having delineated the highest exposures (discussed above) 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 (United States, United Kingdom and USSR - the Franch 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 with the remaining percentage due to cesium-137 and carbon-14 internally deposited through ingestion (inhalation contributes negligible amounts).

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 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 roentgens) is about three percent of that from natural sources. The <u>difference</u> in natural background radiation levels at

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* A milliroentgen is 1/1000 of a roentgen.

various localities in the United States can be much greater than all of the whole body exposure from fallout. If one is truly concerned about radiation doses from fallout he then should logically be much more concerned about where he lives - the variation in radiation doses from natural background resulting from living in different places in the United States can be much greater than those from fallout.

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. There has been no observed skin damage, however, 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. There are several factors that may account for these effects, but to date there is no completely satisfactory explanation.

Approximately a 500 roentgen dose delivered by beta particles from fallout debris delivered to the base of the outer layer of the skin tissue (the epidermis) is required to produce erythema (reddening of the 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 over the intervening years. (Graphics No. 4)

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 tower bursts. Crude estimates suggest that the external whole body exposures in these same areas would have been in excess of 75 roentgens from gamma rays[9].

The principal example of skin damage was on the Marshallese people following the heavy fallout on March 1, 1954[4]. (Graphics No. 6) 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. 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 some scar tissue behind the ear of one man, marking the location of a previous deep lesion and permanent loss of pigment in the healed areas in individuals.

Additional cases of skin damage from fallout were observed on some Japanese fishermen aboard the Fukyryu Maru and some American service personnel on the island of Rongerik, as a result of the March 1, 1954 fallout. Also, four service 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.[9a]

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 regions where the amount of fallout was high, i.e., possibly over 75 roentgens whole body dose from the gamma radiation. 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.

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D. Iodine-131

Background Information -

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

Milk is the principal mode of entry of iodine-131 into the body where it is selectively deposited in the thyroid gland. The assumption is usually made that 30 percent of iodine-131 ingested is deposited in the thyroid no matter what the size of this organ may be[10]. 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 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 and yet of low enough energy yield so that the activity was not swept to high altitudes as usual, to be carried, away, diffused and diluted.

<u>The Data</u> -

The highest value of iodine-131 measured in milk by the Public Health Service national network at any time was at St. Louis, Missouri for the period of August 1957 through July 1958[11]. The calculated average dose was 1.5 roentgens to infants' thyroids based on the usual assumption of 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 roentgens at Palmer, Alaska (October 1961 through September 1962) and the third highest was 0.63 roentgens 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 could show values 10 times or so greater than the average for the general region. It is also probable that higher levels of iodine-131 existed in local areas around the Nevada Test Site during periods of heavy testing in the 1950s.

The estimated doses to the thyroid given above 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 radiations 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 the 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 quoting from a National Academy of Sciences report:[11a.]

> " . . . 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 upward . . ."

There can be circumstances where levels of iodine-131 in milk can be a more controlling factor than external gamma exposures - that have hitherto been considered of prime interest for local fallout. Up-to-date techniques and equipment now permit a relatively easy and early surveillance of iodine-131 in the milk supply.

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 similar to calcium. These facts have led to the use of the "strontium unit" defined as one picocurie (2.2 disintegrations per minute) of strontium-90 per grams of calcium.

Strontium-90 may become associated with foodstuffs by surface contamination of plants or by uptake from the soil. During years of relatively heavy fallout surface contamination accounts for more of the 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 springs and summers 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 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 best 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 roughly 1.5 times as great a strontium-90/calcium ratio as does milk alone[12].

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. However, it has a shorter half-life (53 days) and emits beta particles with about one-half the energy of those from strontium-90. For these reasons 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 that of strontium-90[1].

The Data -

About 21 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) and one million curies above this level - estimated by extending the observed data[13]. 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)[14]. In the absence of atmospheric tests these levels are expected to continue to decline except for small transitory rises in the next few springs. The annual (1963) national average was (<u>to come</u>) "strontium units" in milk. This is less than the 34 "strontium units" predicted and should foretell less in the bones than predicted[1].

(In general, predictions in the past 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 those predicted 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 - from internally deposited as well as external radionuclides - has been predicted to be about 465 milliroentgens (0.465 roentgens) accumulated over a 70 year period[1]. (This was based in part on predictions - that now appear to be somewhat too high - of the strontium-90 in the food supply.)

<u>Evaluation</u> -

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 roentgens) - 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 has been going on for such a great time that the rate of production and rate of decay are in equilibrium, i.e., just as much is formed each year as decays away. 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 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[15]. 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 roentgens) per year (the natural background rate).

The Data -

Since nuclear weapons testing started there have been 511 million tons total yield 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 roentgens)[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 roentgens) per year. Thereafter, the activity will slowly decrease but some will persist for thousands of years. (As a purely mathematical exercise - the total dose from carbon-14 produced from all past tests could accumulate to 420 milliroentgens (0.42 roentgens [1], but one would have to live to an age of about 10,000 years to receive all of this exposure.) Of course, whatever radiation level persists, even if quite low, will irradiate future generations.

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, and because of its long radiological half-life, 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, approximately 90 percent of the fission products are fixed in glassy type material formed by the detonation. Secondly, ion exchange between such key fission products as strontium-90 and cesium-137, and the soil results in almost all of the remaining activity being absorbed within a matter of feet perhaps tens of hundreds away from the source[16]. In addition to fission products, tritium may be formed in varying amounts. This radioisotope probably is not greatly influenced by the two factors mentioned in the previous paragraph 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 above acceptable concentrations of tritium to be present in the amount of water present around ground zero of some underground nuclear detonations[16a].

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 -

While the fallout material from atmospheric tests remains in the air some will be inhaled and will irradiate the lungs. This radiation dose to the lungs normally is less than external 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 a much more important route.

The whole body will also receive some exposure from the penetrating gamma rays while the fallout is in the air, but this dose will generally be small compared to the exposure that follows after the debris is deposited on the ground.

Measurements of total fallout activity in air (called gross beta counts) provide only a crude alert system - this is not a reliable procedure for predicting the amount of fallout to be deposed nor the amount of iodine-131 in milk[17]. Because of the transitory nature of the fallout debris remaining in the air (and sometimes because of the particular choice of units used) what may sound like an alarmingly high concentration may, in fact, result in only minor radiation doses.

Although there is no page numbered 25,
there is apparent continuity from 24 to 26

[redacted]

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 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 detonation, this refers only to the water around ground zero. Some dilution is to be expected if it moves off-site and, more importantly, the criterion of acceptability 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 do not constitute the sole supply for a lifetime.

Much less radioactive fallout debris enters the body by inhalation than by ingestion, and while it is in the air outside the body the radiation exposure is much less than after the material has been deposited on the ground and would not constitute the sole supply for a lifetime.

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 relatively high blast pressures.

One level at 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, 75-100 miles from the point of detonation at the Nevada Test Site[21].

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 is in this case 70-150 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 but in some cases audible sharp cracks and pops.

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

<u>The Data</u> -

Although the blast wave decreased 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 (17 kiloton) nuclear explosion[21]. All together about $50,000 has been paid for structural damage claims from all tests at the Nevada Test Site. There have 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.

<u>Evaluation</u>-

The predictive procedures developed resulted in greatly minimizing off-site damage from blast effects. In fact, there have been only incidents of single window damage 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 occurs all right outside the eye (the inverse square law), the image formed on the retina decreases correspondingly in the same proportion. The result is that the thermal dose (in calories per unit area) remains constant though over 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 0.00025 inches (10 microns) in diameter which is generally taken as about the diffraction limit for the human eye, i.e., light waves will bend slightly as they pass through a small opening such as the pupil of the 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 lesions (damage) on the retina less than 50 microns in diameter probably would not be detected by an eye examination. Actual functional impairment of vision probably would not start to occur if the lesions were mild and less than 50 microns 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 do exhibit a slower rate of delivery than low yields (say, a million tons versus 20 thousand tons). However, high yield detonations (as well as low yield) at high altitudes show a relatively rapid rate of production of thermal energy. This, together with the fact that the thermal energy traverses less atmosphere in reaching the eye than from low altitude bursts, made high altitude and high yield bursts particularly troublesome. (Graphics No. 6)

The Data-

There have no recorded eye injuries to persons off-site. A few individuals have complained of temporary eye impairment. Four military personnel participating in the Nevada tests have received eye injury -

only one of which resulted in a severe visual handicap. 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[21a]. (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 retinal injury and 20/100 when looking away from this area. 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 retinal damage. The 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 looking away from this area, recovering to 20/50 and 20/80 in a month, and one year later was 20/40 in one eye and 20/60 in the other in the area of retinal damage.

(Experimental rabbits were exposed under nighttime conditions to the high altitude shot on August 1, 1958. Lesions with diameters of about 500 microns were observed out to 345 miles - the farthest distance at which rabbits were exposed. Although there are differences between the eye of a rabbit and man the data indicate that large yield high altitude bursts may involve some hazard to the human eye out to the horizon so long as the point of burst is in direct line of sight. This applies only to the instant of burst. As a fireball rises above the horizon the instant of high thermal energy release has past. Also, normal human reflexes of blinking or turning away should further insure.)

<u>Evaluation</u> -

Past procedures employed of closing highways and air lanes and keeping large yield high altitude shots (near or ?) below the horizon (check this) at the instant of burst have resulted in no reported injury to the eyes of persons off-site.

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 iodine 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 described in Reference 22:

> 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%. 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[23]. This resulted in a diminution of the amount of sunlight received on the ground.

As a crude comparison, the 14 million ton 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 20,000 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 precipitations, where the moisture conditions in the atmosphere are most favorable for this effect.

Evaluation -

The most inclusive evaluative statements made are found in References 22 and 24.

> " . . . 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)

[redacted]

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 non-cohesive 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 depth into the ground. Because of the above factors, it is necessary to analyze each situation to predict possible ground motions and structural responses.

ug?

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

[redacted]

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, they 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.[25]

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 ordinarily be subjected to ground motions of 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 the benefits 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 is resulting in a steady improvement in methods of prediction of ground motions for planned events.

The fact that the ground motions from underground nuclear explosions are different in some respects from those from an earthquake and the need to predict marginal damage to structures for such explosions requires a new approach. The analytical procedures for structural response generally are valid and can be applied. However, it is necessary to obtain direct test information.. For these purposes the Atomic Energy Commission is spending over $1,000,000 annually. 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 this decision. 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), then why has there been so much concern expressed? There are probably several reasons.

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

Secondly, in the absence of positive proof otherwise the prudent assumption is accepted that for every little 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 where there is 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 other bases, as noted next.

Thirdly, 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.[10, 10a] 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 . . ."

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

The last two points - the necessity of balancing benefits against risks and the establishment of radiation protection guides for the controlling of industry rather than for identifying a serious health hazard - have been two main sources of misunderstanding. They are subtle points to a layman and yet they must be understood if radiation fallout levels are to be properly evaluated.

To relate hazards from one human enterprise to that of another is an abhorrent and controversial task and yet to do so may add some perspective to living in a 20th century world. For example, it has been reported that in one year's time (1962) approximately 600,000 children in the United States under 5 years of age accidentally swallowed toxic materials resulting in 450 deaths, and a much larger number of serious and crippling illnesses. Many other comparisons have been made such as our nation's annual death toll on the highway being 40,900 and 28,500 more fatalities in the home, 4,300,000 disabling injuries occurring in the home every year with 2,000,000 more at work.

There have been disagreements about the appropriateness of comparing the risks of automobile accidents with those from fallout because, as the argument goes, in the first case an individual has a choice, while in the second he does not. This is really not so. One really has no choice about using automobiles and other vehicles if he is to be a member of present day society. Nor does one have a choice when he is hit unexpectedly because of faulty driving by the other fellow.

Likewise, there are other inherent risks of living in this 20th century world. Congressman Chet Holifield expressed this concept during the Congressional Hearings on Fallout in August of this year when speaking of new articles on fallout:

> " . . . we are faced with certain factors in this world that we have to deal with. We have to set up countermeasures of force, and we have to use the instruments which others are using in setting up their forces against us. And it so happens that facing the realities of life, we have had to set up a counterforce to atomic hydrogen weapons.
>
> " . . . And so it seems to me that somewhere in your articles there might be something said in relation to the security of the Nation, and the factual situation that we face in the world, rather than most of the articles, I think, that come out along this line, which are condemnatory of having testing of any kind, and certainly we have been faced with the situation where the development of weapons had to keep pace with the development of weapons in potential enemy countries. And therefore, it wasn't a choice between what we desired 100 percent, but we were faced with a factual situation where we had to do certain things, and the risk has to be assumed by the population just the same as the risk of war, and the

> argument that the individual in the population doesn't have anything to say about it falls flat with me, because the ordinary individual doesn't have anything to say about the casualties of war. . . ."

A fourth reason why concern has been expressed about health risks from fallout may be a confusion of casual relationships, i.e., the identifying or association of nuclear tests with nuclear war.

In August of 1963 Marquis Childs writing in the Washington Post about fallout from nuclear tests and the debate on the test ban treaty stated:

> " . . . Whatever the scientists and statisticians may say, the fear of nuclear pollution - strontium-90 in the Nation's milk doubled in the past year - and the threat of nuclear war are greater than the fear of the Soviet Union . . ."

If this be so, what a miscalculation!

To place in the same category the health risks from fallout from nuclear tests to those from a nuclear war - if this were intended - is completely contrary to all that is known. The health risks from nuclear test fallout may not be zero, but they are minuscule compared to those of nuclear warfare.

Also, there may have been established in the minds of some that nuclear weapons testing and nuclear war go hand-in-hand, i.e., abolish one and the other is automatically abolished. Such a discussion 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 verifying 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.

[redacted]

APPENDIX

SAFETY PROCEDURES AT THE NUCLEAR TESTING SITES

NEVADA TEST SITE

General -

The health and safety of persons was the major consideration in selecting originally the Nevada Test Site and continued to be during the conduct of nuclear tests in the atmosphere. 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. Aerial and surface surveys were made to insure that no one had wandered into the area.

Beyond these controlled areas are wide expanses of sparsely populated land, providing optimum conditions for maintenance of safety. Although the area is only 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. They 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 though the out-of-door exposure was far from hazardous.

[redacted]

Before each and every nuclear detonation at the Nevada Test Site, a panel of experts weighed carefully all of the factors that insured safety. On the panel were representatives from the fields of public health, medicine, meteorology, fallout phenomenology, blast 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 principal cause for the delays was weather conditions, i.e., to insure minimum fallout in populated areas. The U. S. Weather Bureau 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 second 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 meteorological 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.

[redacted]

Since long distance blast pressure propagation is strongly dependent on wind profile stucture, calculations are made for many directions and distances from the test site where possible window damages may occur. At times it was necessary to recommend a shot delay to await a wind change which would cut blast pressures to non-damaging levels. In other to improve blast calculation techniques, a network of especially sensitive microbarographs is operated at as many as 17 off-site locations to record actual shot-produced pressures in Nevada, California, and Utah.

Full monitoring coverage was provided off-site by the U. S. Public Health Service under contract 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 are 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 Semi-annual (now annual) Reports to Congress and the U. S. Public Health Service's monthly publication, Radiological Health Data.

[redacted]

Weather Predictions -

The Weather Bureau Research Station was started in 1956 to study the meteorology of the Nevada Test Site. In late 1957 it became responsible for providing meteorological support of 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 in the map (Graphics No. 8), 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 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 all nuclear weapons tests.

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 Meteorological Center (NMC) at Suitland, Maryland. The latter Center processed 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 meteorological conditions, adjusted the NMC information to make forecasts having the highest possible accuracy for NTS.

On the day prior to each nuclear weapons test, a formal detailed briefing was given to the Test 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 one or more subsequent briefings just prior to arming each device.

Radiological Surveillance -

Routine programs were conducted continuously within a radius of approximately 300 miles from the Nevada Test Site by the U. S. Public Health Service. During each nuclear event, the capability for monitoring in the downwind area is intensified.

Aircraft Monitoring

The U. S. Public Health Service owned and operated two aircraft for cloud sampling. 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.

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 instruments, 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 stand-by basis.

Air Sampling

There were thirty permanent air sampling stations in operation 24 hours per day in the area surrounding the NTS at distances up to 180 miles distance. (Graphics No. 9)

The air samplers used were high volume motors, drawing air through an 8" x 10" glass fiber filter. When deemed desirable, a secondary activated charcoal cartridge is added for the collection of gaseous fission products. Flow rates were approximately 50 cubic feet per minute (cfm) for the glass fiber filter alone and 25 cfm with the charcoal cartridge added. Glass fiber filters were 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 were assayed with a 400 channel gamma scintillation spectrometer, using a steel shield for a 4" x 4" NaI (TI) crystal with a Cs^{137} peak resolution of eight percent for identification of specific gamma-emitting isotopes.

Film badges were routinely distributed to about 50 locations and to approximately 200 people living in these localities. Film badges were 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.

Milk samples were 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 with one milk cow. In the event that radioactivity was found in any area additional samples were collected.

Water Samples

Water samples were in general collected monthly from approximately 30 sources. 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 meteorology, 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, Virginia, Hazelton-Nuclear Science Corporation, Palo Alto, California and Holmes &Narver, Inc., Los Angeles, California, 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 $8,000,000.

In addition, there 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. Also, in May 1963 a new Biology Division at the Lawrence Radiation Laboratory at Livermore, California was formed with one of its prime missions to investigate problems dealing directly and indirectly with radioactive fallout, especially iodine.

APPENDIX

SAFETY PROCEDURES AT THE NUCLEAR TESTING SITES

PACIFIC TEST SITES

General -

U. S. 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. (Graphics No 7) Notification of locations of these areas and times that the restrictions were in effect were made by issuance of Notices of Airmen through the Federal Aviation Agency and Notices of 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 Navy and Air Force Air Weather Service. To assist in analyzing the weather data and to predict other results such as 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.

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

Radiological Surveillance

Radiological safety (Rad-Safe) was a separate Task Unit within the Joint Task Force organizations. Rad-Safe responsibilities included procuring, storing, and issuing Rad-Safe equipment, the issuance and processing of film badges, the maintenance of personnel radiation exposure records, supervision and monitoring of decontamination and 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 off-site populated islands in the vicinity of the test area and periodic collection of 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.

Off-Site Monitoring

Off-site monitoring stations were located on populated islands out to a distance of about 1,000 miles from the test zone. Samples of soil, vegetation, fruits, water and marine life were collected before testing began and repeated sampling was conducted during and after testing ceased, to determine the background levels of radioactivity in the area and to determine whether there were increased levels in the same area resulting from the test series.

Environmental Safety

During Operation Dominic (1962) there were 34 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 a fallout trajectory forecast for the surface, 10,000, 20,000 and 30,000 feet winds out to 12 to 24 hours, and a predicted radiation exclusion area based upon predicted winds. 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 prepared for use of advisory 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. The program consisted of radiological surveillance of a network of 19 monitoring stations 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/Tongarev, 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 by Task Force Project Groups and Weather Groups. Background stations on Tutuila, 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 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.

Bio-environmental Monitoring

The bio-environmental program for Operation Dominic was under AEC contract with the University of Washington, Seattle, Washington. 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.

Table 1.

Radiation Exposures from Natural Background and Medical Sources

Natural Background (annual exposures)	Roentgens
Total	0.085 - 0.20
Gamma rays (from territorial sources) and cosmic rays	0.1 (varies)
Potassium-40 (internal)	0.018 (varies)
Carbon-14	.001
Medical Exposures	
Chest X-ray (per exposure)	0.2
Back X-ray (per exposure)	0.4
Photoflurogram (per exposure)	about 0.5 - 2.0
Gastro-intestinal series	about 30.

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.

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SUGGESTED GRAPHICS

(Suggestions for Graphics would be most welcome. Due credits will, of course, be given.)

No. 1. Map outlining world areas identifying location of testing sites.

No. 2. Drawings of larger and smaller particles falling from different altitudes.

No. 3. Drawing of globe showing tropopause, stratosphere, etc.

No. 4. Photograph of Alamogordo cattle.

No. 5. Marshallese beta burns.

No. 6. Photograph of persons on Hawaiian beaches watching high altitude shot in summer 1962. (Where can one be obtained?)

No 7. Map of Pacific Test Sites.

No. 8. Weather Bureau Stations.

No. 9. Air Sampling Stations.

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