AD 277 677

ONR Report ACR-72

AN EVALUATION OF THE NEED FOR FILTRATION SYSTEMS TO PROTECT SHELTERED PERSONNEL FROM RADIOACTIVE FALLOUT

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MAY 1962

Office of Naval Research
Department of the Navy
Washington, D.C.

CONTENTS

FOREWORD

The objective of this report is to review the hazards associated with situations involving acute radioactive contamination of the atmosphere and to evaluate the need for air filtration systems to protect personnel in various types of structures in such situations. Discussions with Civil Defense officials and Naval groups indicated that a compilation of facts and conclusions concerning this problem would be useful.

As indicated by the title, this report concerns only radioactive contamination of the air and makes no attempt to evaluate the hazards associated with biological and chemical types of contamination. The biological effects of the three agents are entirely different, though protective measures may have much in common. To attempt an integrated evaluation of the hazards posed by all three was considered neither practicable nor desirable at this stage.

The material presented has been drawn from the following sources: (a) from the open literature and, to a lesser extent, from the classified literature; (b) from interviews and visits to installations; and (c) from personal experience. Most of the members of this Company are trained and experienced in the field of atomic energy. Some of the group have participated in studies of a population accidentally exposed to acute fallout (Marshallese accident, 1954), and, as will be seen, the experience gained from these studies is pertinent to the evaluation of the present problem.

The material is presented in several sections. The various types of events which may lead to atmospheric contamination, such as laboratory and industrial accidents and, particularly, atomic warfare, are reviewed briefly in the first section of the report: "Sources of Airborne Radioactive Contamination." This is followed by the section "The Hazard of Internal Absorption of Radiation Particles." This section has been given considerable emphasis in this report in view of the importance of an evaluation of the hazard in forming a basis for estimating the need for special filtration systems. The section "Useful Air Filtration Systems for Protection Against Airborne Radioactive Contamination" presents recommendations for efficient, readily available, and adaptable filter systems that appear most reasonable after surveying all types of air-cleaning equipment. The section on "Airborne Radioactive Contamination Detection and Alarm Systems" establishes requirements, lists available instrumentation, and assesses the merits of various types of alarm systems for the detection of a contaminated atmosphere. The final section, "Comments and Conclusions" sums up the findings of this investigation.

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Manuscript submitted: April 7, 1962.

Chapter I

SOURCES OF AIRBORNE RADIOACTIVE CONTAMINATION

This section is concerned with the causes of entry of radioactive contamination into the air, the distribution of particle sizes, and the radioactivity of particles produced in the various kinds of contamination events.

Events which can result in the airborne dispersal of radioactive particles are: reactor accidents, detonations of nuclear weapons, accidental contaminating events with or without fission occurring involved in transporting and handling nuclear weapons, and accidental or deliberate spreading of radioactive sources. Past accidents which have involved radioactive sources have been fairly well localized, but their possible bearing upon radiological warfare must be considered.

Of the several reactor accidents which have been reported, only one, the Windscale accident (1), resulted in the contamination of an area outside of the operating establishment. In this case, fission products from ruptured fuel elements entered the atmosphere via the air cooling stack and were dispersed over the neighboring countryside. The hazards associated with this incident were largely produced by radioiodines which, as gases, were not stopped by the exhaust filtration system. This marks these isotopes for special attention in the event of similar accidents in the future. While there was sufficient contamination of the nearby areas to preclude the use of local dairy products for about two weeks, no injury to persons was reported.

Nuclear weapons are by far the most important potential source of radioactive fallout. Contamination from bombs arises mainly from the release of fission products (2). The uranium and plutonium which have escaped fission contribute to a more limited extent. On the other hand, the fissile material will be the major source of contamination in weapons accidents not involving fission. In some explosions there may also be contributions of contamination from materials activated by neutron capture in the various elements present in the vicinity of the explosion.

Fission products are formed in the approximate ratio of 110 pounds per megaton of fission yield. In terms of radioactivity this is comparable, initially, to 100 million tons of radium. The initial decay rate, however, is very rapid and the activity at 24 hours is 1/6000 of that at one minute. Even at 24 hours this is sufficient radioactivity to give, if spread uniformly over an area of 10,000 square miles, a radiation intensity of 2.7 roentgens per hour at a level three feet above the ground. At the end of a week the intensity will have diminished to about one-tenth of the 24-hour value.

The total radioactivity incorporated into fallout depends upon the extent to which the ball of fire touches the ground surface. In a surface burst, large amounts of earth, dust, and debris are taken up into the fireball in its early stages, becoming intimately mixed with the fission products, and forming a tremendous number of small particles bearing radioactivity. The larger pieces of contaminated material fall to the ground near ground zero within an hour or so. Some fifty percent of the total fallout will be deposited on the ground within a few hundred miles of the explosion. The smaller particles are carried higher and farther. Particles of a few thousandths of an inch or less may take more than a day to fall and will travel hundreds of miles.

The principal event in which radioactive particulate matter has actually constituted a major hazard to human beings occurred in connection with the accident of 1 March 1954 in which an unexpected shift in the winds resulted in radioactive contamination of several inhabited atolls, principally Rongelap, Utirik, and Ailingnae, in the Marshall Islands (3), and of the Japanese fishing boat, the No. 5 Tukuryu Maru (4). This accident will be described in greater detail under the section on biological hazards.

Contamination aboard the fishing boat ranged from a low of 10 mr/h in the fish hold to 150 mr/h in wet rope on the upper deck when the activity was first measured on 19 March 1954. A small amount of the radioactive "ashes" was saved in a relatively pure state by a crew member and studied at Kyoto University. The "ashes" had an appearance similar to that of white sand. Under a microscope the particles looked white and smooth with some uneveness and with two to four black spots two to three microns in size on the surface. The mean diameter of the particles (the average of their short and long diameters) ranged mostly from 100 to 400 microns, averaging 257 microns. The ratio of the minimum to maximum diameter of a particle averaged 0.74, and ranged from 0.3 to 1.0. There was no direct correlation between the size of a particle and its radioactivity. Chemically, the chief constituent of the particles was calcium carbonate. The calcium carbonate originated in the coral island which was the site of the detonation, and the radioactive fission products were carried by the fragments from the island.

Other data indicate that the fallout consisted of particles ranging in size from 0.0001 to 0.02 inch in diameter. A cigar-shaped area of contamination about forty miles wide extended over two hundred miles downwind and some twenty miles upwind from the point of detonation.

The northwestern tip of Rongelap atoll, an island fortunately uninhabited when the fallout occurred, received 2300 roentgens during the first thirty-six hours after the fallout started. The inhabited islands were only some twenty-five miles south from this highly contaminated island, but the shape of the dose contours was such that, as indicated above, these islands were subjected to a relatively light exposure.

REFERENCES

1. Windscale – The Committee's Report, Nuclear Eng. 2:310-512 (1957) (Summary of Command Paper 302, "Accident at Windscale No. 1 Pile on 10 October 1957," HMSO, London, 1957)

2. U.S. Armed Forces Special Weapons Project. "The Effects of Nuclear Weapons," Samuel Glasstone, ed., U.S. Atomic Energy Commission, 579 pp., Washington, D.C., 1957

3. Cronkite, E.P., Bond, V.P., and Dunham, C.L., eds., "Some Effects of Ionizing Radiation on Human Beings: A Report on the Marshallese and Americans Accidentally Exposed to Radiation from Fallout," U.S. Atomic Energy Commission, Rept. TID 5358, 114 pp., Washington, D.C., 1956

4. Shimizu, S., et al., "Radioactive Dust from Nuclear Detonation; Survey on the Radioactive Contamination of the No. 5 Fukuryu Maru," Bull. Inst. Chem. Research, Kyoto Univ. Suppl. Issue, 1-3, 1954

Chapter II

THE HAZARD OF INTERNAL ABSORPTION OF RADIATION PARTICLES

INTRODUCTION

This section is concerned with the biological effects to be anticipated when personnel are exposed to airborne radioactive contamination. Any consideration of a possible need for air filtration systems designed to prevent such exposure must be based upon an accurate assessment of these biological effects and of the consequences which would possibly attend failure to provide adequate filter protection. The following comments involve not only data gleaned from an extensive literature search, but also an interpretation of data made by the medical officers who conducted this portion of the project. The majority of these officers are full-time research workers actively engaged in atomic medicine and radiobiology.

It is believed that even without the protection of filters the amount of fallout material entering exposed buildings will be too small to endanger inhabitants through either penetrating gamma radiation or beta radiation of the skin. Thus the probability of tissue damage from external sources may be summarily dismissed. It is, rather, the internal absorption of small amounts of airborne radioactive particles which might pose a hazard for persons in shelters. Consideration will therefore be restricted to those potential hazards arising from any particulate sources of radiation which may be expected to invade the body.

Experience shows that radioactive contamination of the air presents a hazard in various situations such as in: (a) radium and uranium mines and/or processing plants; (b) the processing and separation of fission products from plutonium and uranium in atomic energy industries; (c) nuclear reactor accidents; (d) the application of radioclements in agriculture, industry, and research; and (e) fallout from accidental or purposeful explosion of nuclear weapons. As has been pointed out, atmospheric contamination associated with detonation of atomic bombs will be given primary consideration in this report.

PHYSICAL PROPERTIES OF FALLOUT MATERIAL

In order to evaluate the potential biological hazards of internal absorption of radioactive material, some of the physical properties of fallout must be kept in mind. All fallout is particulate in form, but the size and nature of the particles depends to some extent on the physical and chemical characteristics of the soil in the detonation area (1). For instance, the fallout associated with detonations of bombs in the Pacific Islands, which are primarily coral in nature, as exemplified by that of the Castle detonation of March 1, 1954, is of a white, powdery consistency and composed largely of incinerated coral mixed with fission products (2). Aside from the radioactive component, the calcium oxide of the material was in itself irritating to the skin and mucous membranes due to its caustic nature. Fallout produced from other types of soil would vary considerably in chemical and physical makeup, color, and particle size. That produced from siliceous soils would probably be somewhat less irritating. The bulk of fallout material is made up largely or inert matter, the radioactive particles comprising a relatively small component. While in practice the radioisotopes are usually incorporated closely with the inert material, it is possible that some particles will consist entirely of compounds of radionuclides.

As we shall see, the particle size of fallout material is of extreme importance in regard to hazards arising from absorption into the lung spaces, less so from absorption into the gastrointestinal tract. As will be brought out later, only the smaller particles are readily

absorbed into the lungs. Particle size in fallout tends to be largest close to the detonation site and becomes smaller as the distance of the fallout from the site of detonation increases (1). This is based on experience associated with detonations in the Proving Grounds in the Pacific Islands as well as in Nevada. Thus, fortunately, the areas of heaviest fallout near the site of detonation are associated with less hazard of entry of fallout particles into the lungs, since the particle sizes are too large for more than negligible absorption into this organ. At the greater distances to which the smaller particles are carried, the factor of dilution reduces the hazard from lung absorption.

It has become evident from our experiences with human beings and animals in the Pacific Islands and the Nevada Test Site that although a large number of fission products are present in fallout material, relatively few gain entrance into the body. The amount of these deposited in the body from ingestion and inhalation of this fallout material was insufficient to contribute appreciably to the radiation effects observed.

Larger quantities of the long-lived fission products, such as strontium and cesium, are produced during the extended period of reactor operation than are produced in a single event such as a nuclear detonation. In the case of reactors, problems with fission products result when the fuel element cladding is breached. Radioactive particulates can also be present around operating reactors because of activation of structural materials and dusts inside the reactor. The particles would have the normal size distribution associated with corrosion products and natural dust, and the quantity of radioactive material per particle would be dependent upon the neutron flux as well as the nature of the material being irradiated. The particles resulting from separation processes are again characteristic of the particular process and methods of generation. In general, such particles will have a large quantity of inert material associated with them (3).

The solubility of fallout material is another important factor influencing internal absorption. The various radionuclides in fallout are present mainly as oxides having little solubility in water or in the digestive juices of the gastrointestinal tract. Therefore, most of these compounds are not absorbed appreciably into the body. However, the oxides of strontium and barium, and the element iodine, are soluble and find their way into the blood, bones, and thyroid gland. They are, therefore, the critical radionuclides in early fallout (1). The fission products in the 1954 (Castle) fallout were found to be about 10 percent soluble in water (4).

In addition to the fission products present in fallout material, there may be small amounts of unconsumed fissionable material and activated materials from the environment. The small quantities of these materials that have been found in fallout do not present any acute hazard but might conceivably present a long-term hazard, particularly in regard to long-lived alpha-emitting materials.

PHYSIOLOGICAL FACTORS RELATED TO THE INTERNAL HAZARD

Next to be considered are the physiological factors which determine the fate and ultimate hazard of radioactive particles taken into the body from the atmosphere. Among these are (a) character of respiration, (b) filtering effects of the upper respiratory passages, (c) various clearance mechanisms, and (d) physiological state of the respiratory system, e.g., vascularity, and viscosity of the mucous (2,4).

Since the upper respiratory passages act as a filtering mechanism for larger particle sizes, they may accumulate appreciable quantities of inhaled material. Almost all particles larger than 5 microns are filtered out by the nose (3). On the other hand, only particles of less than one micron actually reach the alveoli of the lungs. Other organs of the body will receive material from the lungs or upper respiratory passages if the material is soluble or brought to them as a result of lung clearance activities, such as phagocytic removal or ciliary expulsion.

In the near vicinity of nuclear explosions, the airborne particles with which radioactivity is associated are usually so large as to be trapped in the upper respiratory passages by

mechanical impingement and sedimentation. Due to saturation humidity, electrostatic effect of particle surface charges in the lung passages is of little importance in determining the fate of inhaled particles (5).

With insoluble beta and, more particularly, alpha emitters, the localization of radiation from point sources in the upper respiratory tract (or elsewhere) may give exposure rates several hundred times the calculated value based on uniform distribution. On the other hand, it may be pointed out that at least in some studies with rat skin using Sr^{90}-Y^{90}, the effect of concentrating the same amount of radioactivity into point sources versus that of uniform distribution was the production of fewer tumors in the case of the point source distribution (3). This insoluble material is removed from the nasal passages and bronchial tree by ciliary action and mucous secretion; these processes remove material over periods of hours to weeks, depending on the depth of the deposit (5). A substantial part is removed to the mouth where it is expectorated or swallowed. As a result of the latter process, a sizable fraction (50 to 75 percent) of the larger inhaled particles are distributed to the lower gastrointestinal (G-I) tract where they may be absorbed into the circulation or, if quite insoluble, eventually excreted. If not absorbed, alpha emitters within the G-I lumen have little effect. Unabsorbed beta emitters could, however, produce injury of the G-I tract. Because of the eventual major transport to the G-I tract of inhaled as well as ingested radioactive substances, particularly those which are soluble, the G-I tract has in recent years come to be considered a major critical organ for internal radiation. In most cases, due to longer transit time as well as greater concentration, the lower large intestine is the G-I area of greatest exposure.

The respiratory fate of the smaller particles (1 micron) is quite different. These penetrate to the alveoli and may be deposited there. If insoluble, they may be removed quite slowly over periods of weeks or months, particularly if they are also of high density. Removal occurs by phagocytes which engulf and carry particles, sometimes to the edge of the ciliated epithelium of the terminal bronchioles, but (perhaps 50 percent) also to the regional lymph nodes by way of lymphatic channels (3). Where a particle cannot be handled by the phagocyte due to size or toxicity, the alveolar sac may close in and wall if off with fibrous tissue.

It is to be noted that concentration and retention of particles are often much greater in pulmonary lymph nodes than in lung parenchyma. Coupled with the fact that lymph nodes are more radiosensitive, it would appear that these lymph nodes rather than lung could be the critical organ for small radioactive particles. The dose that will produce lung cancers (as well as pulmonary fibrosis and pneumonitis) in animals appears at the present time to be of the order of 1000 rads (3). However, this figure assumes uniform distribution whereas point sources, such as alpha emitters, may result in local dosages several hundred times the average, both in lymph nodes and in lung parenchyma.

There appears to be a salient point to be derived from the fact that the two main divisions of the respiratory system (upper respiratory and alveolar) differ in the major particle retention mechanism, particle size retained, and particle clearance characteristics. This point is that sampling procedures need make no finer distinction in particle size than does the human body (in order to predict the respiratory fate of the particles, degree and duration of exposure, etc.). On this basis it has been suggested that the first stage of a two-stage sampling apparatus should have an efficiency of collection of 80 percent or more for 5μ particles, dropping off to zero efficiency at about 1μ, while the second stage should be 100 percent efficient above 1 or 2μ, dropping off for smaller sizes in accordance with the size selective characteristics of the alveoli (5). The two-stage apparatus should deposit the active particles with sufficient space between them to permit individual particle examination by radioautography. By this means it would be possible to determine the number of active particles and the activity per particle. By introducing known absorption media it would be possible to determine the penetration characteristics of the radiation. Repeated measurements spaced in time would determine the decay rate of the particulate matter.

For further improved evaluation of the effects of inhaled radioactive particles, it has been stressed that the influence of pathological lesions, age, physiological states, and breathing patterns on the deposition, clearance, and retention of particles in both upper and lower respiratory tracts should be determined. It has, for example, been noted that a lower respiratory

frequency and concomitant increased tidal volume results in increased deposition of inhaled submicronic particles (3). Ciliary insufficiency and resultant accumulation of mucous and debris may occur in asthma and other respiratory diseases. Increased mucous viscosity may be present under conditions of emotional stress. Possible synergism of radiation and chemical toxicity should be studied.

Methods should be developed to determine physical and physiological characteristics of small particles in the electron microscope range. There is a real possibility that much of the activity at later times and at greater distances from nuclear explosions may be resident on particles of less than 0.1 micron, and relatively little information is available on the retention of the smaller size particles by the human. Preliminary experiments in human beings with a submicron-size sodium chloride aerosol show deposition to be somewhat higher (63 percent mean) than predicted by theory and to be related to the breathing pattern of the individual (cf. above) (6).

Analyses of cadaver lungs should be made wherever possible and correlated with pathology at autopsy. In this connection there is a recent (1960) report (7) on the present radioactive fission products in human lungs in Vienna. These were found by gamma spectrometry to be chiefly cerium^{141}, ruthenium^{103}, and zirconium^{95} + niobium^{95}. The same spectrum of radioisotopes was found in the airborne dust of the area. Amounts contained in the lungs were approximately equivalent to the fission products in 100 cubic meters of air. Spectra for liver and muscles were different, showing only the presence of cesium^{137}. The specific activity of the latter was 84 μc per gram of potassium, a value somewhat higher than found by whole-body counting in 1956 and in 1958.

RADIONUCLIDES OF BIOLOGICAL IMPORTANCE

From the foregoing, it may be concluded that only a restricted number of radionuclides are readily absorbed by the human organism. Our consideration of possible filter systems should therefore center upon them, since it is the entry of these few materials into habited spaces which poses a possible personnel hazard.

Mention has already been made of the case of unfissioned plutonium^{239} which may be present as a small fraction of total radioactive particles after a nuclear explosion, or may be present in greater abundance after a reactor accident. Compounds of such heavy elements as this, even though originally soluble, are usually changed to insoluble oxides at the pH of the body. The insoluble alpha-emitting particles are often retained for long periods by the lung parenchyma or lymph nodes. As little as 0.003 μc $Pu^{239}O_2$ introduced into the lungs of mice by intratracheal administration was found to produce malignant tumors (3). The calculated dose (uniform distribution) was 115 rads but may have been much higher at point sources. Administration of 0.06 to 0.16 μc was followed by lung pathology consisting of sterile pneumonitis, fibrosis, and benign papillary cystadenomas in 60 to 80 percent of the mice within 100 days. When absorbed into the circulation, plutonium (which has a physical half-life of 22,000 years) is largely deposited in the skeleton. At this site its biological half-life is very long (2 to 11 years). Morgan states that the maximum permissible amount of inhaled Pu^{239} over an 8-hour period is 0.13 μc if radiation exposure is to be less than 150 rem/70 years (8). According to his conversion figure this corresponds to 0.013 $\mu\mu$c/cc of air. The total radioactivity in a room of 60 cubic meters would be $60 \times 10^6 \times 1.3 \times 10^{-8}$ μc = 0.78 μc. If this room air is replaced every 15 minutes the flow rate is 5.2×10^{-2} μc per minute = 1.15×10^5 disintegrations per minute (d.p.m.), which might be considered a level for alarm signal from air samples. In the National Bureau of Standards Handbook 69, the permissible air concentration for a 40-hour work week is given as 4×10^{-11} μc/cc when lung is considered the critical organ, and 2×10^{-12} μc/cc when bone is considered the critical organ (9).

For the estimate of the more immediate hazards from nuclear events, various radioactive fission products must be considered. Teresi and Newcombe (10) conclude that the principal components in the fallout mixture contributing to the internal dose during the first seven days after fission are iodine^{131}, neptunium^{239}, barium^{140} + lanthanum^{140}, strontium^{89}, zirconium^{95} + niobium^{95}, and yttrium^{91}. The main contributors from 8 to 105 days after burst are:

zirconium^{95} + niobium^{95}, iodine^{131}, strontium^{89}, cerium^{144} + praseodymium^{144}, barium^{140} + lanthanum^{140}, and yttrium^{91}. From 105 to 365 days after fission, cerium^{144} + praseodymium^{144}, zirconium^{95} + niobium^{95}, and strontium^{90} + yttrium^{90} are the principal contributors. Morgan has a table with a similar list of isotopes according to their abundance at various time intervals after fission (8).

According to Teresi and Newcombe, the two radioisotopes that possess the lowest maximum permissible concentrations (m.p.c.) for a single inhalation exposure within 24 hours after fission are iodine^{131} and strontium^{90} + yttrium^{90}. The maximum permissible concentrations for a dose of 15 rem in 90 days (military dose criteria) are, respectively, 8.0×10^{-7} and 1.0×10^{-6} μc/cc of air. In general, for exposure during the first day after fission, the most damaging radioisotopes range in m.p.c. from 5.5×10^{-3} to 5.7×10^{-2} μc/cc for ingestion and from 8.0×10^{-7} to 5.6×10^{-6} μc/cc for inhalation. Nine out of the fourteen most important radioisotopes concentrate in the gastrointestinal tract as the critical organ.

Kilocurie amounts of I^{131} are produced after a nuclear blast. While other radioisotopes of iodine are also produced and may have some transient significance (such as I^{131} with a half-life of 21 hours), it is the 8-day half-lived I^{131} which is of prominence among the airborne radioisotopic particulates in the air following nuclear explosions. In the Windscale accident in England in October 1957, this radioisotope was the one which was of greatest significance in the contamination of the air of the surrounding countryside and, consequently, the grass, soil, and the milk of the area (11).

The hazards of both inhalation and ingestion may be present after air contamination with I^{131}. The I^{131} may be present on insoluble particles (after nuclear bomb explosions) or as iodine vapor (as happened in the Windscale accident). The particulate I^{131} does not remain substantially in the lung, since it shares the fate of "insoluble" silver iodide which is known to be rapidly removed from the lung and moved into the bloodstream (3). The thyroid gland and the gastrointestinal tract are critical organs after inhalation or ingestion. It has been stated that one-half of a dose of radioactive iodine may be deposited in 1/1000 of the body (12). In normal thyroids, 15 percent and 20 percent will reach the thyroid gland after inhalation and ingestion, respectively. Ingestion of a given amount of fission product activity may result on the fourth and fifth day in 20 percent as much dose to the lower large intestine as to the thyroid. The salivary gland and renal tubules are also sites of I^{131} concentration (12).

For ordinary occupational exposure, 0.7 μc of I^{131} is said to be the maximum permissible body burden (9). Half of this (0.35 μc) may be present in the thyroid gland. This amount will deliver 300 to 400 mrep to the thyroid, whereas the lowest amount of radiation that will cause transient alteration of physiological activity of the thyroid is 1000 to 2000 rep (1 to 2 millicuries I^{131}). The body burden will remain less than 0.7 μc if the air concentration is below 3×10^{-9} μc/cc for continuous 24-hour-a-day exposure (9). In an ordinary size room ($4 \times 5 \times 3$ m, or 60 m^3) at this concentration, the total amount of I^{131} is 0.18 μc. Thus, if the total room air is replaced every fifteen minutes by air with this concentration of radioiodine, the flow rate through a filter is 1.2×10^{-2} μc/min (2.6×10^4 d.p.m.), which might be considered a level for alarm signal from the air samples. However, 10 times this level would still provide a relative safety factor of about 500 (see above numbers), so the level of permissible exposure, necessary filtration, and alarm signal could be revised upwards depending upon exigency of conditions. It may be noted that the permissible concentration for a military criterion, as stated previously, has been considered to be 8.0×10^{-7} μc/cc or 250 times the above value for chronic occupational or continuous exposure.

Two isotopes of strontium, Sr^{89} and Sr^{90}, are of major concern in fallout. They are both beta-emitting isotopes with half-lives of 53 days and 28 years, respectively. The possible hazard to large populations from widespread, long-term fallout of Sr^{90} with subsequent introduction into the food cycle and eventually the skeletal system of man has been well emphasized in recent years. A practical requirement for filtration protection from this isotope over such extended periods of time appears highly improbable. On the other hand, Sr^{89} is prominent among the possible internal emitters during the first few weeks after nuclear fission.

Strontium, like radium, is chemically similar to calcium and is deposited in the calcified part of the bone tissue. In the other mammalian tissues only trace amounts (less than 1 percent of the administered amount) are deposited. The fate of inhaled radioactive strontium particles will depend, as in so many other cases, on the particle size and on the solubility of the strontium. If soluble or solubilized, the bone is clearly the critical organ, but if insoluble the lung may be the critical organ. After oral ingestion (or transport to the gastrointestinal tract following inhalation) half to two-thirds of the strontium is excreted in the faeces and a small percent in the urine (13).

Age and dietary factors are important in the fate of strontium taken internally. Young rats have been found to retain more radioactive strontium than old animals, and retention is larger on a low-calcium diet than on a high one (13,14).

The toxicity of Sr^{89} has been demonstrated in work at Argonne National Laboratory (15). It was found that a single intraperitoneal injection of slightly less than 5 μc of Sr^{89} per gram body weight to adult rats produced 50 percent mortality in 30 days. The LD_{50} for 30 days for Sr^{89} in young mice is reported by Brues to be 8 μc per gram body weight. Forty-nine percent of the animals which had received 5 μc/gm and had survived for 200 days died before 250 days. Fourteen percent of these animals had developed bone tumors. Concerning the toxicity of Sr^{90}, Finkel and co-workers found the LD_{50}/30 days for mice to be 6 μc/gm body weight and for dogs as low as 0.15 μc/gm body weight (16). The doses of the isotope reported to induce carcinogenic transformation of bone tissue in mice and rats is less for Sr^{90} (0.009-0.4 μc/gm body weight) than for Sr^{89} (0.7-1.6 μc/gm). The maximum permissible body burden for Sr^{89} is 4 μc according to National Bureau of Standards Handbook 69, and for Sr^{90} is 2 μc (9).

In Handbook 69, the permissible air concentration of Sr^{89} for the 40-hour week is given as 3×10^{-8} μc/cc where bone is the critical organ, and 4×10^{-8} where lung is the critical organ. For an 8-hour exposure, Morgan allows about 1.0×10^{-6} and 1.3×10^{-6} μc/cc, respectively (8). Using the value 3×10^{-8} and calculating, as previously, for a 60-cubic-meter room, the air of which is replaced every 15 minutes, the critical radioactivity flow rate is about 3.5×10^{5} d.p.m. For comparison it may be noted that for a military criterion dose of 15 rem in 90 days, obtained from constant exposure for 1 day, Teresi and Newcombe (10) allow 3.2×10^{-6} μc/cc of air or about 100 times the maximum permissible chronic exposure for an ordinary working population, and for a dose of 150 rem in 30 days, 6.9×10^{-5} μc/cc of air is allowed for one day.

Cesium^{137} is a fission product radioisotope which also appears to be of appreciable importance from the long-range standpoint of widespread fallout. While its half-life (33 years) is long like that of strontium ^{90}, it poses different problems biologically since it is a gamma- rather than a beta-emitter, and chemically and metabolically it resembles potassium rather than calcium. It is, like Sr^{90}, generally introduced into the body through the food cycle. The maximum permissible total body burden has been estimated at 50 to 100 microcuries. Studies with the whole-body counter on Marshallese people three years after exposure showed the most prominent gamma-emitter to be Cs^{137} with an average body burden of 0.02 microcuries (17).

Muscle is the most critical organ for soluble cesium^{137}, and it has been estimated that 48 percent of any dose reaches this tissue by ingestion and 36 percent by inhalation (18). The biological half-life is relatively short (13 to 17 days) so only chronic environmental exposure (diet or atmosphere) will maintain an appreciable body content (19).

National Bureau of Standards Handbook 69 gives the permissible air concentration of Cs^{137} for a 40-hour week as 6×10^{-8} μc/cc and for a 168-hour week as 2×10^{-8} and 5×10^{-9} μc/cc for the two periods of exposure – the lung is again the critical organ. For 24-hour exposure and an eventual dose of 15 rem in 90 days, Teresi and Newcombe allow 9.0×10^{-5} μc per cc of air for Cs^{137} + Ba^{137}.

THE MARSHALL ISLANDS ACCIDENT

In view of the importance of the studies of the Marshallese people exposed to fallout in relation to the problem under disucssion, it seems pertinent to review briefly some of the major findings in these people. References 20 through 27 are references on the medical surveys of the Marshallese.

The accident occurred in March 1954, following detonation of an experimental nuclear device at Bikini in the Marshall Islands. An unpredicted shift in winds caused deposition of significant amounts of fallout on four nearby inhabited Marshall Islands and on twenty-three Japanese fishermen aboard their fishing vessel, the Lucky Dragon. Sixty-four inhabitants of the island of Rongelap, 105 nautical miles from the detonation, were exposed to the largest fallout, receiving an estimated dose of 175r of whole-body gamma radiation, indeterminate beta-ray dose to the skin from fallout deposition on the skin, and internal absorption of radioactive fission products. Eighteen Rongelap people, away on a nearby island (Alingnae), where less fallout occurred, received about 69r with proportionately less contamination of the skin and internal absorption of radionuclides. There were also 28 American servicemen on Rongerik Atoll who received about 70r and 137 Marshallese on Utirik Atoll who received about 14r.

The people were evacuated from their islands about two days after the accident. During the first 24 to 48 hours after exposure, about two-thirds of the Rongelap people experienced loss of appetite and nausea, and a few vomited and had diarrhea attributable to the radiation exposure. Many also experienced itching and burning sensations in the skin, and a few complained of burning and watering of the eyes. Following this, they showed no effects until about two weeks after the accident when skin burns and loss of hair developed due largely to beta radiation of the skin. As a result of their gamma exposure, their blood elements were depressed to as low as one-half of the normal levels before gradually recovering.

There were no deaths that could be related directly to radiation exposure. However, it is probable that the dose was near the lethal range judging by the degree of blood cell depression that developed.

Numerous radiochemical analyses of the urine showed that definite amounts of radioactive material had also been absorbed internally. It should be emphasized that the Marshallese lived for two days under heavily contaminated conditions on their home island, making little or no effort to avoid eating or breathing the material, or to protect the food and water from becoming contaminated. Thus, these people lived in about as bad a contaminated situation for two days as can be imagined. In spite of this, urine analyses showed that the accumulation of isotopes exceeded the maximum permissible levels for lifetime exposure only for radioiodines. Due to radioiodines absorbed, it is estimated that the thyroid glands of the people received 100 to 150 rad of radiation but with no apparent effect. Damage to the gastrointestinal tract by passage through it of an estimated three millicuries of fission-product activity was not believed to have added materially to the gastrointestinal effects.

In the Marshallese, in spite of this heavy exposure to fallout, urine analyses showed rapid dwindling of activity so that by two years after exposure the radionuclides present, including long-lived ones such as Sr^{90} and Cs^{137}, were hardly detectable. This leads one to the conclusion that acute exposure to fallout which is not lethal does not present either an acute or long term hazard from internally deposited isotopes.

REFERENCES

1. U.S. Armed Forces Special Weapons Project, "The Effects of Nuclear Weapons," Samuel Glasstone, ed., U.S. Atomic Energy Commission, 579 pp., Washington, D.C., 1957

2. Conard, R.A., "The Effects of Fallout Radiation on the Skin," in "Symposium on the Shorter-Term Biological Hazards of a Fallout Field... 1956," edited by Gordon M. Dunning and J. A. Hilcken, pp. 135-142, U.S. Govt. Printing Office, Washington, D.C., 1958

3. National Academy of Sciences, Committee on Pathologic Effects of Atomic Radiation (1956 Report), National Academy of Sciences-Nat'l. Research Council, Washington, D.C., (Particularly Appendix III, "Report of the Subcommittee on Acute and Chronic Effects of Radioactive Particles on the Respiratory Tract")

4. Cohn, S.H., et al., "Internal Radioactive Contamination of Human Beings Accidentally Exposed to Radioactive Fallout Material," Naval Radiological Defense Lab., San Francisco and Naval Medical Research Inst., Bethesda, Md., Rept. USNRDL-TR-86, 50 pp., 1956

5. Burnett, T.J., "Sampling Methods and Requirements for Estimating Airborne Particulate Hazards," Oak Ridge National Lab. Rept. CF-32-11-1, 1952

6. Stannard, J.N., and Morrow, P.N., "Retention of Sub-Micron Aerosols in the Human Respiratory Tract," in "Symposium on the Shorter-Term Biological Hazards of a Fallout Field...1956," edited by Gordon M. Dunning and J. A. Hilcken, pp. 189-195, U.S. Govt. Print. Off., Washington, D.C., 1958

7. Schonfeld, T., et al., "Radioactive Fission Products in Lungs," Nature 185:192-193 (1960)

8. Morgan, K.Z., "Internal Dose from Short-Lived Radionuclides," in "Symposium on the Shorter-Term Biological Hazards of a Fallout Field...1956," edited by Gordon M. Dunning and J. A. Hilcken, pp. 149-160, U.S. Govt. Print. Off., Washington, D.C., 1958

9. National Committee on Radiation Protection, "Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure," U.S. National Bureau of Standards, Handbook 69, U.S. Govt. Print. Off., Washington, D.C., 95 pp., 1959

10. Teresi, J.D., and Newcombe, C.L., "A Study of Maximum Permissible Concentration of Radioactive Fallout in Water and Air Based Upon the Military Exposure Criteria," Naval Radiological Defense Lab., San Francisco, Rept. USNRDL-TR-182, 136 pp., 1957

11. Chamberlain, A.C., "Relation Between Measurements of Deposited Activity after the Windscale Accident of October 1957," United Kingdom, Atomic Energy Research Establishment, Harwell, Rept. AERE-HP/R-2606, 1958

12. Werner, Sidney C., ed., "The Thyroid; A Fundamental and Clinical Text," New York: Hoeber-Harper, 1955

13. Kidman, Barbara, Tutt, M.L., and Vaughan, J.M., "The Retention and Excretion of Radioactive Strontium and Yttrium (Sr^{89}, Sr^{90}, and Y^{90}) in the Healthy Rabbit," J. Path. Bact. 62:209-227 (1950)

14. Copp, D.H., Axelrod, D.J., and Hamilton, J.C., "The Deposition of Radioactive Metals in Bone as a Potential Health Hazard," Am. J. Roentgenology 58:10-16 (1947)

15. Brues, A.M., "Biological Hazards and Toxicity of Radioactive Isotopes," J. Clin. Invest. 28:1286-1296 (1940)

16. Finkel, M.P., and Brues, A.M., "Sequelae of Radiostrontium Administration to Dogs," (abstr.) Radiation Research 3:224 (1955)

17. Conard, R.A., et al., "Effects of Fallout Radiation on a Human Population," in "1st International Congress of Radiation Research," Burlington, Vt, 1958, Proceedings, edited by Douglas E. Smith, New York:Academic Press, Radiation Research, Suppl. 1, 1959

18. Robertson, J.S., and Cohn, S.H., "Radiotoxicity of Internally Deposited Radioactive Material," in "Atomic Medicine," 3rd ed., pp. 233-258, Baltimore:Williams & Wilkins, edited by C. F. Behrens

19. Ballou, J.E., and Thompson, R.C., "Metabolism of Cesium^{137} in the Rat: Comparison of Acute and Chronic Administration Experiments," Health Physics 1:85-89 (1958)

20. Conard, R.A., "Medical Survey of Rongelap People Five and Six Years After Exposure to Fallout Radiation," Brookhaven National Lab., Upton, N. Y., Rept. BNL-609 (T-179), 1961

21. Conard, R.A., et al., "March 1957 Medical Survey of Rongelap and Utirik People Three Years after Exposure to Radioactive Fallout," Brookhaven National Lab., Upton, N. Y., Rept. BNL-501 (T-119) 29 pp., 1958

22. Conard, R.A., et al., "Medical Survey of the Marshallese Two Years After Exposure to Fallout Radiation," J.A.M.A. 164:1192 (1957)

23. Cronkite, E.P., et al., "Twelve-Month Postexposure Survey on Marshallese Exposed to Fallout Radiation," Brookhaven National Lab., Upton, N. Y., Rept. BNL-384 (T-11) 15 pp., 1955

24. Bond, V.P., et al., "Medical Examination of Rongelap People Six Months After Exposure to Fallout," Operation Castle, Addendum Report 4.1A, Rept. WT-937, 1955

25. Cronkite, E.P., Bond, V.P., and Dunham, C.L., eds., "Some Effects of Ionizing Radiation on Human Beings: A Report on the Marshallese and Americans Accidentally Exposed to Radiation from Fallout," U.S. Atomic Energy Commission Rept. TID-5358, 114 pp., 1956

26. Conard, R.A., "The Biological Hazards of a Fallout Field" (in press), in "Symposium on Radioactivity in Man," Vanderbilt University, April 1960, edited by G. R. Meneely, Springfield, Ill., C. C. Thomas

BIBLIOGRAPHY

National Academy of Sciences, Subcommittee on Inhalation Hazards, "The Biological Effects of Atomic Radiation," Summary reports, Nat'l. Acad. Sci.-Nat'l. Res. Council, Washington, D.C., 1960

U.S. Congress, Joint Committee on Atomic Energy, "The Nature of Radioactive Fallout and Its Effects on Man," hearings before the Special Subcommittee on Radiation, 85th Congress, 1st. session, U.S. Govt. Printing Office, Wash. 25, D.C., 1957

Chapter III

USEFUL AIR FILTRATION SYSTEMS FOR PROTECTION AGAINST AIRBORNE RADIOACTIVE CONTAMINATION

A study has been made of the various types of air filtration equipment and air filtration systems. The term "air cleaning" (1,2,3,4) is used in this report in a more limited sense than in the literature, because "air cleaning" usually includes the removal of unwanted gases from the air stream. Gas removal is a specialized problem (3). There is no known equipment that will remove all gases. Neither is there any equipment for removing the noble gases. Argon^{41}, for instance, is usually handled by dispersal and natural decay. This investigation has, therefore, been limited to the problem of removing solid particles from the air stream.

Certain reasonable comparisons can be made between possible fallout particles and particles found in everyday air filtration problems. Impurities contributing to atmospheric pollution include carbon from incomplete combustion of fuels, particles of earth and sand, ash, stone, lint, and many forms of organic matter. An air cleaning problem, apart from gaseous content, can be classified with respect to the kind of dirt to be removed: lint, coarse dirt, fine dirt, smoke, smudging dirt, organic matter, and pollen (5).

In a fallout situation, the particulate impurities would probably correspond closely to the coarse and fine dirts. Coarse dirt can be moved about by high winds, heavy street traffic, or by foot traffic. Fine dirt normally constitutes the bulk of atmospheric dust (5). Following a bomb burst close to the ground a certain amount of earth that is carried aloft becomes mixed with fission products and sooner or later returns as radioactive fallout (6). For the purposes of this report, we are assuming that the bulk of this fallout will be in the form of dirt in various particle sizes.

The simplest filtration system available is the mat-type filter such as is used in mechanical ventilation systems and household hot-air heating systems to catch the bulk of coarse dirt before it enters the system (1,3,5,7). These mats are made from a variety of materials such as felt, cellulose, and Fiberglas. They are usually installed at the air intake and will stop the bulk of coarse dirt from entering the system (1,7,8).

The most efficient filter is the so-called "absolute" filter (3). This is a pleated-paper strainer-type filter that will filter better than 99 percent of all particulate matter down to 0.3 micron, as shown by the dioctyl phthalate (DOP) test. They are now available in materials other than paper, are heat and acid-proof, etc. The Navy has also developed superior filters (9).

Such filter units have become standardized both as to sizes and efficiency. Because of the requirements of various atomic energy establishments in recent years, the demand for these filters is such that they can be obtained readily from commerical sources.

A typical standard size is the 24 × 24 × 8-inch size, rated 1000 fpm with an air velocity of 35 fpm through the filtering media. The initial cost of the filter element is approximately $50 (1958). Its annual operating cost, including maintenance and electric power, would be approximately $12 per 1000 cfm.

The disadvantage of these efficient filters is their fairly low dirt-holding capacity which, in turn, determines the useful like of the filter element (5). Therefore, the best all-around filtration system will be of a two-stage design consisting of an inexpensive, easily replaced coarse or "roughing" filter in the air stream ahead of the more efficient absolute filter. The roughing filter, by removing the bulk of the coarser particles, will prolong the useful life of the ultrafilter. This combination will extend serviceability and will efficiently filter better than 99 percent of airborne particulate matter down to 0.3 micron.

Certain laboratories such as the Air Cleaning Laboratory of the Harvard School of Public Health and certain naval laboratories provide services as central clearing houses for information on gas and air-cleaning problems (2,3,4,8,9,10).

REFERENCES

1. Friedlander, S.K., et al. (n.d., decl. 1952), Handbook on Air-Cleaning (particulate removal), Harvard Univ., School of Public Health, Rept. AECD-3361; NYO-1572, 114 pp.

2. Third Atomic Energy Commission Air Cleaning Conference held at Los Alamos Scientific Laboratory, Sept. 21-23, 1953. (1954, decl. with deletions 1957), Atomic Energy Commission, Division of Engineering, Rept. WASH-170 (Del)

3. Fourth Atomic Energy Commission Air Cleaning Conference held at Argonne National Laboratory, 1955 (n.d.; Part 2 decl. 1957), Atomic Energy Commission, Division of Reactor Development, Rept. TID-7513, Part 1-3 (Part 3 for Official Use)

4. Fifth Atomic Energy Commission Air Cleaning Conference held at Harvard Air Cleaning Laboratory, Boston, June 24-27, 1957 (n.d.), Atomic Energy Commission, Division of Reactor Development, and Harvard Univ., Boston, School of Public Health Rept. TID-7551, 163 pp.

5. Carrier, W.H., et al., "Modern Air Conditioning, Heating, and Ventilating," 3d ed., New York: Pitman Pub. Corp., 592 pp., 1959

6. Shaw, H.E., "Survival in Fallout Areas" (period covered: January 1958-June 1958), Chemical Warfare Labs., Army Chemical Center, Md., Rept. CWLR-2272, 39 pp., 1958

7. Kattner, L.E., and Gifford, J.F., "Fiberglass Air Filters for Hot Laboratories," Hanford Works Rept. HW-30781, 23 pp., 1954

8. Rossano, A.T., Jr., Silverman, L., and First, M.W., "A Preliminary Field Survey of Air Cleaning Activities at Atomic Energy Commission Facilities, September-November 1950," Harvard Univ., Boston School of Public Health, Rept. NYO-1580, 51 pp. (1951, decl. 1957)

9. Office of Naval Research (personal communication)

10. First, M.W., et al., "Air Cleaning Studies; Progress Report for Feb. 1, 1950 to Jan. 31, 1951," Harvard Univ. School of Public Health, Rept. NYO-1581, 222 pp., 1951

Chapter IV

AIRBORNE RADIOACTIVE CONTAMINATION DETECTION AND ALARM SYSTEMS

INTRODUCTION

Since the early days of the Manhattan Project it has been necessary to measure the extent of airborne contamination. This need has resulted in the development of a variety of air monitoring instruments for the detection of alpha, beta, and gamma radiation. The feasibility of employing such instrumentation as a passive defense measure against radioactive fallout from an atomic attack is considered in this section with the intention of (a) establishing the requirements of a suitable detection and alarm system, (b) reviewing the availability of instrumentation to meet these requirements, (c) comparing the relative merits of each type of instrument, and (d) making specific recommendations in consideration of the above.

SYSTEM REQUIREMENTS

As the mixed fission products of a nuclear excursion undergo radioactive decay they produce gamma radiation in addition to alpha and beta emissions (1,2). The problem of detection is, therefore, simplified in that an alpha or beta counter is not necessary in an air monitoring system for defense measures.

The factors governing the choice of a detection system in their order of importance are: reliability, availability, economy, and simplicity.

SYSTEM ANALYSIS

Basically, a detection system for airborne contaminants may be operationally subdivided into a sensing element, an amplifier, and a display (3).

The sensing element of a gamma detection system may be one of three types: air ionization chamber, Geiger-Muller tube, or scintillation crystal. The air ionization chamber seems best fitted only for special detection problems. Its construction requires unusual care in regard to electrode insulation, and it is much more sensitive to humidity than is the G-M tube or the scintillation crystal. Its gamma efficiency is low, and it is not readily available. The scintillation-type counter overcomes many of the serious problems of high resistance and insulation. Because of its simplicity and greater reliability, it promises to replace both the G-M counters for low-intensity gamma detection and the ionization chamber for high dose-rate gamma survey (4). Scintillation counters composed of a plastic scintillator in combination with a photomultiplier are essentially plug-in units available as stock items in a variety of forms.

The amplification of a photomultiplier pulse presents no problems because of the relatively low counting rate requirement (see Alarm Level below). There are many count rate circuits which will accomplish this function equally well, and the choise will obviously be dictated mainly by economy.

The display requirements would be a count rate level indicator and an alarm activator. Usually a voltage indicates the count rate so that a voltmeter equipped with meter relays triggered at preset count rate levels fulfills the requirements. The count rate level indicator may be dispensed with if only an alarm requirement exists and if some other provision is made to indicate that the equipment is functioning. Obviously, any other desired function, such

as closing off the ventilating system air flow or activating special detection units, may be accomplished by means of additional circuits actuated by the relays.

COST CONSIDERATION

An analysis of the costs indicates that further study should be made with a view to arriving at more economical systems. Satisfactory count rate meters are priced around $300; a photomultiplier, around $50. Plastic scintillators are so inexpensive (less than $5) as to be insignificant, but installation costs would be at least $100, including any circuit modifications and alarm units. Thus the total cost would approach $500. Undoubtedly a package system could be developed which would cost considerably less than the combined cost of separately purchased components of the system.

ALARM SIGNAL LEVEL

Radioactive contaminants originating from natural sources and the continuing program of nuclear tests are always present in the air. The intensity of this radioactive "background" changes rapidly from place to place and from time to time. The alarm level must, of course, be set so that large increases in background activity due to temperature inversion or other causes will not result in frequently occurring false alarms.

Background increases of several hundredfold are possible in certain areas. It seems reasonable to state from an investigation of this matter that any contaminating process that raises the level of airborne gamma radioactivity to more than 500 times the normal background should activate the alarm and any other automatic protective features of the system. Levels below this are not of concern unless persistent over long periods, in which case the normal government monitoring systems will suffice to detect them. Peak gamma backgrounds arising from bomb test fallout have been observed at Brookhaven National Laboratory since the beginning of a monitoring program in 1949. These count rates have never exceeded 200 times the base level. For the particular G-M counter and geometry used, this was approximately 20 counts per minute (5,6). It would seem then that a setting of 500 times normal background would prevent most, and possibly all, false alarms.

CONSTANT AIR MONITORING

In general, air monitors fall into one of the following types: fixed filter monitors, automatic filter monitors, and automatic impactor monitors.

The most obvious method of measuring airborne contamination is to suck air samples as large as possible through a filter. Particulates caught in the filter can then be counted in a radiation counter. This procedure has been actively used for many years in radioactive material production areas and would seem to lend itself most readily to civil defense application.

Most modern buildings, and those designated as mass personnel shelters, are provided with a central air-conditioning system which is fitted with filters capable of collecting at least larger size particulates. The air-conditioning system can, therefore, be converted to an air monitoring system by placing a laboratory monitor at the filter to monitor the particles deposited thereon. A filter-based air monitor of this type is now in operation in the Alternating Gradient Synchrotron at Brookhaven National Laboratory. The system employs a G-M tube to detect the radioactive deposition. An artificial source is placed near the detector to provide a constant counting rate slightly above background fluctuations. This allows a low-level relay to be set so that a second system and failure indicator signal can be activated upon failure of the first system. The signal from the G-M tube is fed into a Baird-Atomic Counting Rate Monitor, Model 410, equipped with two model 451-C meter relays, made by the Assembly Products Company. This has proved to be a very satisfactory system and has been in operation for over a year with essentially no maintenance.

Certain contaminants such as plutonium are of an extremely toxic nature even at very low levels and, therefore, would require a much more elaborate system for their detection than the fixed-filter monitor previously described. Automatic monitors are sensitive instruments which are capable of detecting low levels of activity. There are basically two types of these: automatic filter monitors and automatic impactor monitors.

In the automatic filter monitor the activity is brought to a detectable level by pulling the air through a continuously moving strip of filter paper upon which the activity is concentrated. An instrument of this type is in use at the Brookhaven National Laboratory (7,8). The instrument consists essentially of three units: filter paper transport, an air pump, and a counter unit. The counter unit includes a beta-gamma mica-window G-M tube and associated scaler, and a scintillation alpha counter and scaler.

Automatic impactor monitors are similar to the automatic filter monitors except that the air is impacted on an opaque moving tape instead of being drawn through a filter strip. An automatic impactor monitor using commerical masking tape has been developed and is in service at the Savannah River AEC installation (9).

Automatic monitors are superior in that they are sensitive to low-level radiation and produce a continuous record of airborne contamination. But they are impractical for general use because they require constant servicing of the tape. Such installation, however, could be limited to defense stations set up to alert areas.

REFERENCES

1. U.S. Armed Forces Special Weapons Project, "The Effects of Nuclear Weapons," Samuel Glasstone, ed., U.S. Atomic Energy Commission, 579 pp., Washington, D.C., 1957

2. "Accident at Windscale No. 1 Pile on October 10, 1957," Report of the Committee of Inquiry, HMSO, London, 1957

3. Handloser, J.S., "Health Physics Instrumentation," New York: Pergamon Press (International Series of Monographs on Nuclear Energy, Div. 5: Health Physics, v. 1), 182 pp., 1959

4. Campbell, D.C., "Radiac; an Introduction to Radiological Instruments for Military Use," U.S. Armed Forces Special Weapons Project, Radiological Defense, v. 4, 1950

5. Hartmann, E., Brookhaven National Laboratory (personal communication)

6. Weiss, M.M., "A Study of the Airborne Radioactivity at Brookhaven National Laboratory from the Nevada Tests, March through June 1953," Brookhaven National Lab., Upton, N. Y. Rept. BNL-252, 18 pp., 1953

7. Kuper, J.B.H., Foster, E.H., and Bernstein, W., "Monitor for Radioactive Dust," Nucleonics 6(No. 4):44-47 (April 1950)

8. Weiss, M.M., "Area Survey Manual; Area Radiation Detection, Instrumentation Maintenance, and Results" (rev. ed.), Brookhaven National Lab., Upton, N. Y. Rept. BNL-344 (T-61), 1955

9. Collins, D.C., "A Continuous Monitor for Airborne Plutonium," E. I. Du Pont de Nemours and Co., Savannah River Lab., Augusta, Ga., Rept. DP-188, 1956

Chapter V

COMMENTS AND CONCLUSIONS

RELATIVE IMPORTANCE OF THE INTERNAL RADIATION HAZARD

In recent years the problem of radioactive contamination in nuclear warfare, in industry, and scientific laboratories has been recognized as a serious hazard. It has been estimated that 60 to 70 percent of the casualties in nuclear warfare would result from fallout radiation. The accidental exposure of some 250 Marshallese people to fallout radiation, following detonation of an experimental nuclear device in the Pacific Proving Grounds in March 1954, brought the problem of fallout to the front. The experience gained from a study of these people has since then formed the basis for much of our civil defense and radiation safety planning.

It seems quite likely that for fallout to represent a significant radiation hazard it would have to be visible to the naked eye in falling.

Generally, fallout situations present three possible types of exposure to man: whole-body radiation from the gamma component; skin irradiation largely from the beta component; and internal irradiation due to absorption of radionuclides via the gastrointestional tract and, also, to a lesser extent, through the lungs. It is recognized that the gamma radiation from fission-product material in fallout is by far the most serious of the hazards and may result in whole-body radiation exposure sufficient to result in radiation sickness and death. Positive protection against this gamma radiation is afforded by shielding. This is emphasized in the importance given to the shelter program by Civil Defense authorities in this country.* At the present time the best medical treatment may allow one to recover from a dose of radiation twice that which would have caused death without treatment. When one considers the fact that an ordinary home basement offers a protection factor of 10 to 20 (i.e., reduces the dose inside the basement to 1/10th to 1/20th of the outside dose) and that fallout shelters are designed to provide at least a protection factor of 100 or more, it is quite clear that dependence on shelters rather than on medical care-after exposure is the only answer to the problem. Moreover, medical personnel and facilities would be totally inadequate to provide the necessary treatment for a large number of radiation casualties.

If sufficient fission product contamination of the skin occurs, resulting irradiation of the skin may produce so-called "beta burns" which can be moderately disabling. However, personnel in closed buildings or basement shelters would not likely become contaminated sufficiently to result in such burns. Prompt decontamination of the skin with soap and water would prevent burns if significant skin contamination did occur.

A review of the available information leads one to the conclusion that in the case of fallout, the internal absorption of radioactive materials is not an acute hazard. Even in the open in a fallout situation, one would receive a lethal dose of whole-body gamma radiation before internal accumulation of radioactive materials could be lethal. These statements are based largely on the significant conclusions that were drawn from the Marshallese studies. Here the facts indicated that: (a) although the people were exposed to fallout in the air, on the ground, and in their food and water for two days with little or no effort to avoid the radioactive material, radioiodine was the only radionuclide accumulated in excess of the maximum permissible level, (b) inside of a year or two, their body burdens of radioactive materials could not be distinguished from those of unexposed Marshallese people; and (c) no acute or chronic effects have been apparent as a result of their internal exposure.

*It should be pointed out that the basements of many larger public buildings in communities offer adequate protection against fallout without further alteration. The public appears to be generally unaware of this fact.

Most of the material from fallout that gains access to the body does so via the gastrointestinal tract rather than the lungs because most particle sizes in acute fallout situations are too large for inhalation into the lungs. Therefore, in these situations lung damage is not likely to be either an immediate or a late hazard. The particle size of fallout may be smaller at greater distances from the point of detonation, and inhalation into the lungs is a possibility. However, at such distances fallout is more diluted and the hazard is correspondingly reduced.

During the early period after fallout, the gastrointestinal tract, along with the thyroid gland, probably receives the largest doses of radiation from fission products gaining access into the body. Following the acute period of fallout danger, persisting contamination with long-lived isotopes may present a long-term, chronic radiation problem particularly from the point of view of radiation of the lung and bone.

In view of the above considerations, it is apparent that the hazards from the small amounts of radioactively contaminated air that would enter closed buildings and shelters is negligible compared with the hazard of penetrating gamma radiation effects from fallout outside of the building. In a closed building or basement, the amounts of fallout that would enter through cracks in doors and windows would be of small import.

PROTECTION AGAINST RADIOACTIVE ATMOSPHERIC CONTAMINATION OF SHELTERS AT MOST PUBLIC BUILDINGS AND HOMES

In view of the above considerations and in view of the expense involved in installing special filtration systems against radioactive contamination of the atmosphere, it is considered that for shelters in buildings occupied by the population at large the installation of such special filtration systems is neither feasible nor necessary. In order to substantiate this conclusion, let us examine the situation in which no special filtration systems are installed in public buildings or homes at the time of atmospheric contamination resulting from nuclear warfare. Let us assume that the shelter has a safety factor of one hundred against the gamma radiation and that the shelter entrance is of the baffle type which will allow ready exchange of air with the remainder of the basement area. At the commencement of fallout or as a result of the sounding of an alarm or other warning, all doors and windows in the building could be immediately closed and the ventilation system turned off to minimize the entrance of any fallout into the building. If a previous blast wave has broken windows, particularly in the basement shelter area, these open areas should be closed off to prevent the excessive entrance of fallout into the basement. Unless the shelter area is greatly overcrowded, personnel can remain easily for a 24-hour period without opening windows or doors for ventilation purposes. At the end of 24 hours, the fallout would have ceased and the air would no longer be radioactively contaminated. Windows and doors could then be opened for sufficient periods of time to accomplish ventilation.

Thus the period of atmospheric contamination, which is dependent on the length of time of fallout, is an important consideration in the overall evaluation of the situation. In the case of the Marshall Islands accident, it is estimated that after the detonation of the bomb (about 0600), the fallout on Rongelap Island (100 miles away), began about four hours later and continued for a total of about twelve hours. Based on this and other fallout experiences, it therefore seems reasonable to assume that a period of fallout of over 24 hours would be extremely unlikely, even if the enemy were to attack in two waves.

It has been ascertained that unless a basement shelter is overcrowded, it will contain sufficient air (with the added exchange of air with the outside through cracks in doors and windows) to easily sustain life for long periods, certainly until fallout has ceased. The following is quoted from Section III from "Industrial Ventilation" (1). "The need for outside air for respiration, that is, to provide oxygen for the body, is of very minor importance. Enough air for this purpose will usually enter a structure or building by filtration." It is possible that temperature and body ordors may cause some discomfort but would be of negligible importance under the circumstances.

Thus, special air filtration systems to protect against radioactively contaminated air would not be needed in basement shelters, provided ventilation systems are turned off and doors and windows are closed.

CONSIDERATION OF UNDERGROUND SHELTERS AND SPECIAL TYPES OF BUILDINGS

In the case of closed underground shelters, some form of ventilation with intake filtration systems would be necessary. In addition, there are certain types of specialized buildings in which such filtration systems may be indicated. Such buildings would include Civil Defense, governmental, and military nerve centers such as headquarters buildings, communications centers, etc., which are vital to the defense of the country. In addition, large hospitals might be considered in this category. In the case of homes and public buildings discussed in the first category, evacuation of personnel from these buildings would be likely within several weeks after fallout. However, in the case of buildings under the present discussion where long-term occupancy would be a likely consideration, protection against the entrance of contaminated material into the building, either by air intake systems or by personnel entering and leaving the buildings, would be an important consideration. For the sake of comfort and efficiency of such personnel, ventilation systems would probably be needed. Therefore, efficient filtration systems against the entrance of contaminated air would be necessary. In addition, personnel decontamination stations would also be indicated in order to avoid undue contamination of the building. The expense in carrying out the above alterations would be considerable.

In consideration of filtration systems that might be used, the U.S. Army Engineering Command Report , ENGR No. 30 (2), outlines in great detail the filtration systems that would be adequate. The recommended filters are also protective against biological and chemical warfare agents. This excellent report also outlines a design of a decontamination suite. Less elaborate plans might be suitable in some cases.

The use of an alarm system might be indicated in these specialized types of buildings. Such a system should make use of a gamma detector, preferably of the scintillation type. Such an instrument would cause an alarm to sound when the gamma background radiation increased five hundred times. Circuits activated by relays might be used to cut off ventilation or to start special filtration systems functioning.

REFERENCES

1. American Conference of Governmental Industrial Hygienists, Committee on Industrial Ventilation, "Industrial Ventilation; A Manual of Recommended Practice," 6th ed, The Committee, Lansing, Mich., 1960, especially Section III, "Comfort Ventilation"

2. Smith, G.P., et al., "Protection of Structures from Chemical, Biological, and Radiological (CBR) Contamination," U.S. Army Chemical Corps Engineering Command Rept ENGR No. 30, 1959

BIBLIOGRAPHY

"A Method for Evaluating the Protection Afforded by Buildings Against Fallout Radiation," Sept. 1957, Office of Defense Mobilization

"Guide for Fallout Shelter Surveys, Dec. 1958," Office of Civil and Defense Mobilization, Battle Creek, Mich.

Technical Operations, Inc., Burlington, Mass., "Radiological Defense Planning Guide," Commonwealth of Massachusetts, Federal Civil Defense Administration Rept [illegible] 346 pp., 1958