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FACTS ON RADIATION AND FALLOUT

AN APPENDIX TO THE PROTOTYPE MANUAL ON CIVIL DEFENSE ASPECTS OF WATERWORKS OPERATIONS

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PROTOTYPE MANUAL ON CIVIL DEFENSE
ASPECTS OF WATERWORKS OPERATION

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Engineering-Science, Inc.
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FACTS ON RADIATION AND FALLOUT

INTRODUCTION

To put it very simply, fallout is a mixture of radioactivity and dirt. When a nuclear weapon is detonated on or near the ground surface, the physical force and high temperature pulverize and even vaporize a large quantity of earth, mixing it with the fission products and other forms of radioactivity produced by the explosion. As this mixture rises into the atmosphere, it cools and condensation occurs; such that some of the radioactivity becomes incorporated into fused particles of earth of various sizes. As further cooling occurs in the turbulent rising cloud, additional contamination of the surface of the debris particles takes place. In some respects, this process is analogous to water coagulation where the mixing of a chemical coagulant with finely divided suspended matter serves to incorporate the earth material into large particles of floc which then settle when placed in the quiescent environment of the sedimentation basin. In a manner quite similar to the function of alum floc, the particles of earth carry the radioactivity down to the ground surface to form a radioactive deposit termed "fallout".

To devise measures for dealing with fallout we must understand it; how it is created by nuclear weapons, how it is deposited on the earth, how the forces of nature may transport it into our water supplies, and perhaps most important of all, we must understand radioactivity and radiation and their relationship to the health of man. It is the purpose of this appendix to provide some of this vital understanding. For those having a considerable background in nuclear physics and weapon phenomenology, the treatment of the subject herein may appear overly simplified and lacking in technical depth. It should be remembered that this is only a primer in the field of nuclear science and weaponry and that understanding is linked to brevity and clarity and not to technical detail and complexity. The reader is invited to continue his education by reference to the bibliography of technical books and publications appended to this Appendix.

NUCLEAR WEAPONS AND FALLOUT

Fission and Fusion Weapons

The size of a nuclear weapon is usually measured in terms of the energy it yields expressed in equivalent tons of TNT. The "energy yield" of the nuclear bomb dropped on Hiroshima was 20,000 tons of TNT or 20-kilotons (20-KT). As all of the energy of the Hiroshima bomb was formed by the fission of uranium-235, the "fission yield" was also equivalent to 20-KT and about 2.5 pounds of fission products were released.

Today we must consider much larger bombs in terms of the energy yield, as it is now possible to combine the fission of such heavy elements as uranium-235 and plutonium-239 with the fusion of hydrogen to release energy equivalent to missions of tons of TNT. These megaton H-bombs, or thermonuclear devices, depend on fission to provide the high temperature necessary to trigger the fusion reaction and consequently the fission yield may be very much less than the total energy yield. An example will serve to illustrate the difference between energy yield and fission yield. A 0.1 megaton hydrogen bomb (that is 0.1-MT or 100-KT) would release the equivalent energy of 100,000 tons of TNT; but as it might require only a 5-KT fission trigger, it would release only 25 percent of the fission products which arose from the 20-KT Hiroshima bomb. Thus, although the energy yield was 100-KT, the fission yield was 5-KT.

There is the implication in the previous paragraphs that whereas fission reactions produce radioactivity as fission products, fusion reactions produce no radioactivity at all. This is not quite true, since both kinds of reactions create large numbers of neutrons which subsequently produce some radioactivity as they encounter and interact with the chemical elements making up the bomb structure and the surrounding earth. However, the neutron induced radioactivity is likely to be much less significant than that resulting from fission. A comparison of these two kinds of radioactivity will be given in a subsequent paragraph.

A distinction should also be made between the initial or immediate radiation that accompanies the blast and heat waves and the residual radiation associated with the fission products and fallout. Both fission and fusion weapons produce an initial release of radiation, usually arbitrarily defined as that occurring in the first minute after detonation. The amount of this radiation is closely proportional to the energy yield and is emitted directly from the fireball as a consequence of the fission and fusion reactions. The residual radiation is produced by the radioactive decay of the fission products and other radioactivity induced by neutrons. This radiation is emitted at a decreasing rate over a time period extending to months and years and is that associated with fallout.

Types of Bursts

In addition to energy and fission yields, it is also necessary to consider the type of burst. For instance, a nuclear weapon may be detonated high in the air, or at the surface of land or water, or after it has penetrated into earth or water. Each type of burst results in a different distribution of fallout. An "air burst" in which the fireball fails to touch the earth results in the formation of very small fallout particles which travel with upper level winds for long periods and are distributed over a large area with a resulting low concentration of fallout per unit area of land surface. Because of the period of residence of the fission products in the upper atmosphere and stratosphere, a considerable reduction in the amount of radioactivity is achieved by natural radioactive decay. Thus both dilution and decay may reduce the radiological hazard from a high air burst to a negligible level before the material returns to the land surface.

In a "surface burst", the detonation occurs at or sufficiently near the ground surface that the fireball touches the ground. This has the effect, together with the blast wave, of incorporating large amounts of vaporized and crushed soil and rock into the atomic cloud which then function to bring much of the fission products back to earth within a few hours and a few dozen miles of the point of detonation. Under these circumstances, both the amount and surface concentration of fallout radioactivity are much greater and the radiological problem of the waterworks, potentially more serious.

In a "subsurface burst", the center of the nuclear explosion occurs under the ground or under water. Much of the heat and shock are absorbed by the earth or water and the radius of severe damage may be far more limited than in the case of an airburst. However, large amounts of earth or water adjacent to the detonation point will be contaminated. If the burst is at a shallow depth in the earth, a crater will be produced and a large amount of the radioactivity will be associated with crater throwout with a resulting relatively heavy local contamination, but also some regional contamination, depending on the size and height-of-rise of the atomic cloud. As the depth of detonation becomes greater, the amount of radioactivity released is progressively reduced.

It should be evident from the above comments that nuclear detonations at very high elevations or deep in the earth are likely to create only negligible hazards to human health and would cause little difficulty to the water utility. Unfortunately, from the standpoint of military or destructive effectiveness, the surface or near surface burst is the most probable and here we must face a potential local fallout problem of serious proporations.

The Deposition of Fallout

The amount anddistribution of fallout is very much dependent on the type of burst, the energy yield, and, of course, the fission yield. As the surface burst is most likely, our discussion will be limited to the distribution of fallout under this circumstance. Within a very few minutes after a surface detonation, the atomic cloud will have risen to many thousands of feet; in fact, well into the stratosphere if a megaton size H-bomb was detonated. As the turbulence subsides, the particles of fallout begin their long descent to earth. An interesting relationship of energy and fission yield to the initial distribution of fission products in the cloud should be noted. With a small fission weapon, for example, one of only 5-KT of both energy and fission yield, the fission products will be vertically distributed over only a few thousand feet. However, with a 100-KT fission-fusion weapon involving a 5-KT fission trigger, the same amount of fission products (that is the equivalent of 5-KT of fission) would be distributed over an elevation of more than 100,000 feet and an appreciable fraction of the particulate debris would start its earthward journey from the stratosphere. Moreover, because of the greater energy and temperatures of the larger weapon, the particles would be smaller and would consequently settle more slowly. Thus, from the standpoint of fallout hazard, the small weapon may be more damaging than the large.

Following an Hiroshima size or larger burst, significant amounts of fallout will begin to arrive in the immediate vicinity of the blast area about twenty to thirty minutes after an explosion. People some twenty miles away may have an hour to seek protection while those at a distance of one hundred miles may have four or more hours. The fallout will continue to be deposited over an increasingly large area, and may eventually cover several thousand square miles, depending on the energy yield and prevailing winds. It is thus evident that outside the immediate area of blast effects, the most serious problem is that of fallout; that the area effected may be large, but also that a majority of individuals in this area will have an opportunity to take shelter. These considerations are especially important to the large water utility and to the smaller satellite systems of metropolitan areas. If they have prepared protective countermeasures, they should have ample opportunity to execute them. Photographs of the development of an atomic cloud are shown in Figure 1.

The region of severe local fallout lies generally downwind from the point of burst. It is impossible to predict with accuracy how large this area will be or what shape it will take because of the many factors which may affect it. The area of severe fallout from a 5 to 10-MT burst might extend five or ten miles upwind of ground zero (at or below point of burst) and 150 to 200 miles downwind. The pattern would be irregular in outline, but would tend to be cigar-shaped. Deposition would not be uniform, tending to be more concentrated along the axis and diminishing toward the edges. There would undoubtedly be local hot-spots caused by the micrometeorological influence of buildings and terrain features. By the same token, there would probably be small areas within the pattern nearly devoid of fallout.

In summary, the concentration and distribution of fallout from a surface burst and the resulting initial levels of radiation would be determined by:

1. The energy and fission yield of the weapon.

2. The nature of the earth materials coming into contact with the blast wave and fireball.

3. Atmospheric conditions, particularly the direction and velocity of winds up to 80,000 feet. Rain and snow may serve to accelerate the rate of deposition.

4. Nature of the ground surface, especially the presence of water bodies.

The forces of nature may serve to bring about a relatively rapid decontamination of areas contaminated with fallout, but they may also function to concentrate the fallout. Time is by far the most effective decontaminating agent, as the passage of time, especially during the first few hours following the bomb burst, brings about the reduction in radioactivity by decay. The effect of precipitation will generally be to cleanse bare surfaces,

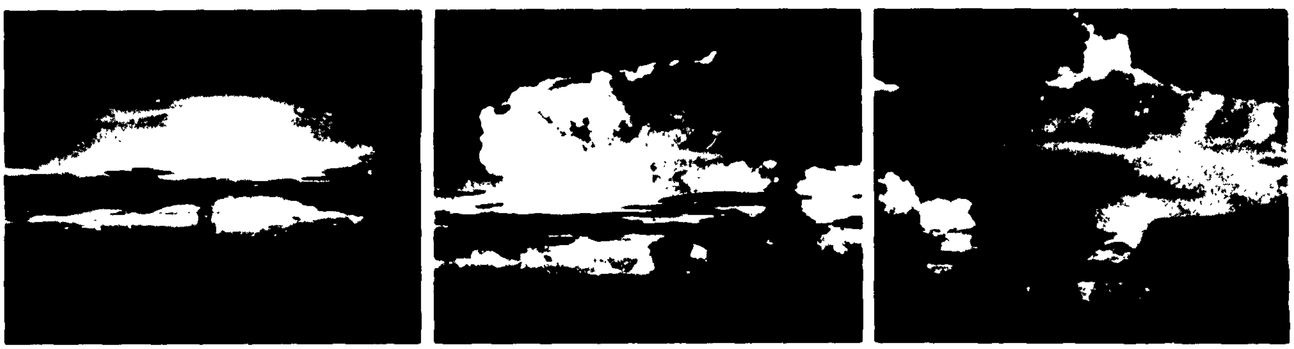


Figure 1.—Progressive stages in the development of atomic cloud formed by nuclear explosion in the megaton energy range near the earth's surface. The mushroom portion went up 10 miles, and spread for 100 miles.

streets, sidewalks, and roofs, of fallout dust. Fallout on plowed or grassy lands will tend to be held and to become a part of the soil. The soluble materials of fallout will be dissolved by rain and carried a short distance into the earth's mantle. In this case, the surface radiation intensity will be reduced by the shielding effect of the earth. Moreover, the absorptive properties of the soil mass will serve to reduce the contamination of both surface and ground waters, especially in the case of the latter.

THE ATOM AND RADIOACTIVITY

To understand atomic energy and the radioactivity that it produces, it is necessary to understand the atom. All matter is made up of one or more simple materials known as elements of which 92 are found to occur naturally. Elements may appear in nature in the pure or uncombined state such as the gases -- oxygen (O), hydrogen (H), and nitrogen (N), or they may combine to form molecules as oxygen and hydrogen do to give us water (H_2O). Other examples of elements are the metals; for example, iron (Fe), copper (Cu), sodium (Na), aluminum (Al), and uranium (U). These generally exist in nature as molecules, often in combination with oxygen as the oxides (Fe_2O_3), and it is only after processing by man that they are available in the metallic form. On the other hand, sodium chloride (NaCl) and aluminum sulfate ($Al_2(SO_4)_3$) are examples of metallic compounds used in the molecular rather than atomic forms.

At the beginning of the 19th century, it was thought that the atom was the smallest division of matter. It is a fact that the atom is the smallest division that we may make of an element and still have it retain its normal and unique elemental properties. However, if the atom itself is divided, we find that the resulting material, the sub-atomic particles, are the same for all atoms!

Atomic Structure

The atoms of all elements contain three primary types of particles -- protons, neutrons, and electrons. The inner core of the atom or nucleus is composed of neutrons and protons, while the electrons are found moving in orbits around the central nucleus. Whereas the neutron is without charge, the proton has a plus charge and the electron has an equal but negative or minus charge. The masses and charges of these particles are very small, but they are accurately known as shown in Table I.

TABLE I

THE MAJOR CONSTITUENTS OF MATTER

Partical	Common Symbols	Charge*	Weight or Mass, grams **
Proton	p, p^1	+	1.66×10^{-24}
Neutron	n, n^1	0	1.66×10^{-24}
Electron	e, e^-	-	9.1×10^{-28}

* An electrical current of only one ampere flowing for one second is equivalent to the passage of 6.2×10^{18} (6.2 billion billion) electrons along a wire.

** One gram of ordinary hydrogen gas contains about two-thirds of a million billion billion protons and an equal number of electrons.

Hydrogen, the simplest of the atoms, will serve to illustrate how electrons, protons and neutrons combine to form atoms and how one element can have different kinds of atoms that are termed isotopes. The most common form of hydrogen (or protium) is composed of a single central proton and a single orbital electron. However, natural hydrogen contains about one part in 7,000 of heavy hydrogen (or deuterium) having both a neutron and a proton in the nucleus, but still a simple orbital electron. Largely as a result of our nuclear energy program, we now have heavy heavy hydrogen (or tritium) containing two neutrons and one proton in its nucleus. These three kinds of hydrogen atoms are termed isotopes of hydrogen. They are essentially identical from a chemical standpoint, but they are quite different from a nuclear standpoint. In fact, tritium is the basis of the H-bomb. Figure 2 illustrates the structure of the atom and the differences among the isotopes of hydrogen. Tritium is a radioactive isotope, or radioisotope, while protium and deuterium are non-radioactive, or stable.

All elements have several isotopes; carbon, for example, has six, (C^{10}, C^{11}, C^{12}, C^{13}, C^{14}, and C^{15}) of which only two (C^{12} and C^{13}) are stable. Some elements have as many as 19 isotopes, all chemically identical, but quite different from a nuclear standpoint. Three of the isotopes of carbon are illustrated in Figure 3.

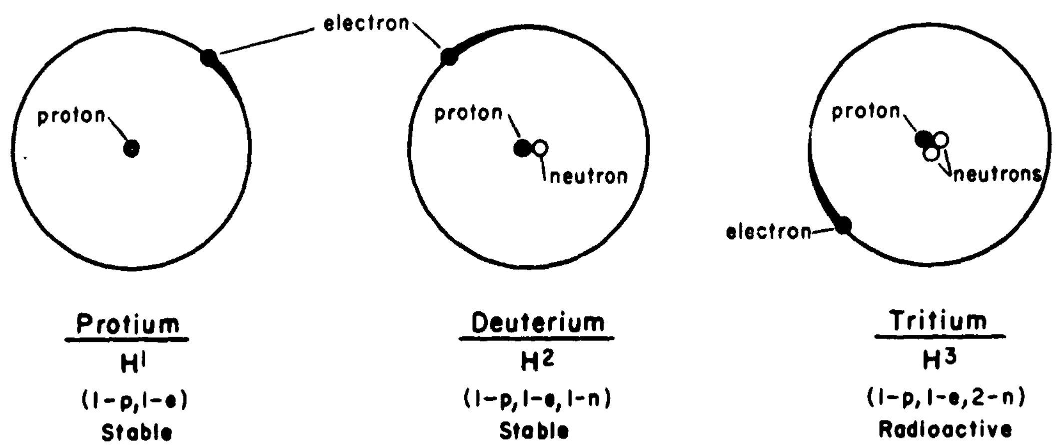
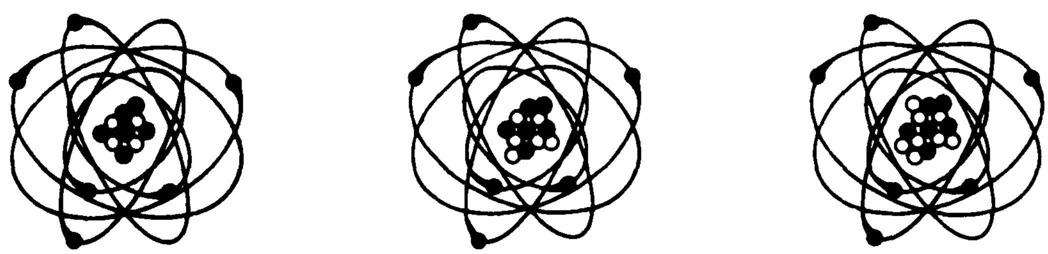


Figure 2.— ATOMIC STRUCTURES OF THE ISOTOPES OF HYDROGEN



C^{10}	C^{12}	C^{14}
(6-p, 6-e, 4-n)	(6-p, 6-e, 6-n)	(6-p, 6-e, 8-n)
Radioactive	Stable	Radioactive

Figure 3.— ISOTOPES OF CARBON

Radioactivity

The essential difference between the isotopes of an element lies in the number of neutrons in the nucleus since all isotopes of a single element must have the same number of protons. If the numbers of protons and neutrons are proper, the nucleus is stable and has no tendency to disintegrate. However, if either a deficiency or over abundance of neutrons exists in the nucleus, there is a tendency toward instability and individual nuclei will ultimately disintegrate, releasing radiation and forming a new nucleus of a different element. Under these circumstances the isotope is a radioisotope and the process of disintegration is termed radioactivity. Carbon-10 and carbon-14 (or C^{10} and C^{14}) of Figure 3 are illustrative of this principle of instability arising from too few or too many neutrons. The process of disintegration is referred to as radioactive decay. It may be looked upon as merely a mechanism by which certain atoms, having a surplus of energy in their nuclei, adjust to a more stable state by releasing energy in the form of nuclear radiations. Generally, the greater the instability (too many or too few neutrons), the more quickly the disintegration occurs and the greater the amount of energy released as radiation. Fission itself is a form of radioactive decay that occurs naturally, but one that man has learned to accelerate so as to release the nuclear energy at any rate he chooses; rapidly in a bomb or more slowly in the nuclear reactor serving an electrical power utility. Unfortunately, as we have seen earlier, fission also results in the fission products of fallout and these include a great many radioisotopes.

The amount of radioactivity (or of radioisotopes) is measured by the rate of disintegration and is most commonly expressed in a unit known as the curie. At one time, the curie was taken as equal to one gram of radium (Ra^{226}), but today it is defined as the amount of radioactivity producing 2.22 million million disintegrations per minute (2.22×10^{12} dpm). As a curie is a relatively large amount of radioactivity, a variety of smaller units are used as shown in Table II.

TABLE II

UNITS OF RADIOACTIVITY

Unit	Symbol	Decay Rate or Disintegration per minute
Curie	c	2.22×10^{12}
Millicurie	mc	2.22×10^{9}
Microcurie	µc	2.22×10^{6}
Micromicrocurie or Picocurie	µ µc or pc	2.22

The extremely small weight of radioisotope necessary to produce a given amount of radioactivity may be illustrated by reference to the Public Health Service 1962 Drinking Water Standards. These Standards allow the consumption of water containing strontium-90 (Sr^{90}) providing the concentration does not exceed 10 µµc / liter. This corresponds to 7.0×10^{-11} mg/liter or 0.07 billionths of a part per million, hardly a concentration measurable by the usual chemical methods employed in the waterworks laboratory. However, by employing relatively common radiation measurement instruments and concentrating the radioactivity by evaporating a few hundred milliliters of water, such measurements are entirely feasible and may be accomplished with acceptable accuracy.

The Radiation From Radioactive Decay

Radioisotopes produce three kinds of radiation of interest to waterworks personnel; alpha, beta and gamma radiation. Alpha radiation is generally produced in the decay of the heavier radioisotopes, for example, radium-226 (Ra^{226}), uranium-235 (U^{235}), and plutonium-239 (Pu^{239}) and is likely to be associated with fallout only in small amounts as a result of failure of all of the U^{235} or Pu^{239} to undergo fission. The alpha particle is very massive in comparison with other forms of radiation, containing two neutrons and two protons. It happens to be identical to the nucleus of the helium-4 (He^4) atom. Because of its great size and double charge, alpha particles have little penetrating power, a few inches of air being sufficient to stop them.

Beta radiation may take the form of either high energy electrons (e^- or β^-) or positrons (e^+ or β^+). Positrons are identical to electrons in weight and charge except that the charge is of opposite sign; it is positive. Beta radiation exposure, especially if resulting from skin contamination by fallout, can result in severe burns. However, radioisotopes emitting alpha or beta radiation can normally pose serious hazards to health only when they have been taken into the body and become a part of the structure of some vital organ. Under these circumstances, the short range of their radiation is actually detrimental as it may result in the entire energy of the radiation being dissipated within the organ.

Gamma radiation is the most penetrating form of radiation from fallout and is the greatest threat of fallout to the unshielded individual. Whereas alpha and beta radiation are particulate, that is, they take the form of small projectiles and have weight, gamma radiation is electromagnetic and in many respects similar to light. However, where a few sheets of paper will stop ordinary light, they pose no barrier at all to gamma radiation. X-rays are very similar to gamma radiation, except that they are less energetic and thus have a lesser penetrating power. The gamma radiation stopping power of various substances is largely dependent on their densities and only to a limited extent on the nature of the elements composing them. For example, it requires 5,600 inches of air to stop 50 percent of a beam of gamma rays, but only 6.5 inches of water, 3.2 inches of concrete, and about 0.5 inches of lead are required to accomplish the same task. Three to five feet of well packed earth are generally sufficient to give adequate protection against the intensities of gamma radiation expected from fallout.

The fission product radioisotopes may emit beta radiation or beta and gamma radiation, depending on the characteristics of their nuclei. The energy of the radiation is also characteristic of the emitting nucleus and determines the penetrating power and hazard of the radioisotope to health. The energy of radiation, regardless of type, is expressed in millions of electron volts (Mev).

Fission and Fusion Reactions

Fission and fusion are the source of energy in nuclear weapons and serve to create the residual radioactivity - the fission products and neutron induced radioisotopes. Nuclear fission is the splitting of heavy nuclei with an accompanying release of energy.

In nature, U^{235} undergoes fission at the rate of 40 atoms per minute per gram with each fission releasing two to three neutrons. When these neutrons strike other nuclei in a critical mass of U^{235}, a very large number of fissions occur in a chain reaction progression. An example of such a reaction is shown below.

$$U^{235} + n^{1} \xrightarrow{\text{FISSION}} \text{Energy} + Sr^{94} + Xe^{140} + 2n^{1}$$

Fission product isotopes of health significance are shown in Table III.

Nuclear fusion is the joining of light nuclei to form a heavier nucleus. Such reactions can only be accomplished under conditions of very high temperature (millions of degrees) and it is necessary to use a fission device to supply this temperature. Fusion reactions, for example, account for the energy of the sun, a fact that has been known from the early 1930's. A likely fusion reaction is illustrated by the equation given below in which two atoms of tritium (H^3) fuse to release energy and form an atom of helium (He^4) and two neutrons (n^1). In this reaction, one gram of tritium would release 49,000 kilowatt hours of energy.

$$H^{3} + H^{3} \xrightarrow{\text{FUSION}} \text{Energy} + He^{4} + 2n^{1}$$

In contrast to the fission products, the atoms formed in fusion are not radioactive. However, the neutrons produced by the reaction will combine with atoms comprising the earth, the structural material of the bomb, etc., to form induced radioisotopes.

Rate of Radioactive Decay - Half-Life

For a particular atom, disintegration is an all-or-nothing reaction. All atoms of a single kind of radioisotope have identical tendencies to disintegrate, but they do not do so at the same time. When a large number of radioisotope atoms are present in a source of radioactivity, the disintegration (or decay) of individual atoms occurs at different times and results in a nearly continuous release of radiation. With the passage of time, the number of unstable nuclei in the source is depleted and consequently the number of disintegrations per minute (or radioactivity) must also diminish, until after a considerable period, the amount of radioactivity remaining may be negligible. To put it simply, but quantitatively, the rate of decay of a radioactive source is proportional to the number of unstable atoms present and to the characteristics of the nuclei of these atoms. As an equation:

Radioactivity (disintegrations/min or curies) = k x N

k = decay constant of nucleus

N = number of unstable nuclei in source

Generally the decay constant of a radioisotope is expressed as its half-life[1], or the time required for one half of the nuclei to undergo decay. This is also equal to the time required for the radioactivity to decrease by 50 percent. The concept of half-life is illustrated in Figure 4 for the fission product strontium-89 (Sr^{89}). Sr^{89} has a half-life of fifty days and emits only beta radiation with a maximum energy of 1.5 Mev. It decays to the stable daughter yttrium-89 (Y^{89}). If the initial radioactivity amounted to 100 μc (microcuries), after 100 days (or two half-lives) only 25 μc would remain, while after 250 days (5 half-lives) the radioactivity remaining would be 3.1 μc.

Table III presents the half-lives, modes of radioactive decay, and radiation energies of several of the fission product radioisotopes. In some instances, both beta and gamma radiation are released; while in others, a disintegration involves only beta radiation. The Sr^{90}-Y^{90} and Cs^{137}-Ba^{137m} parent-daughter groups are of special public health significance because of their long half-lives and in the case of Sr^{90}, the large amount of energy associated with the decay of the Y^{90} daughter. Strontium, being chemically similar to calcium, is a "bone seeker" and the decay energies of both parent and daughter (a total of 2.80 Mev) are absorbed by the bone marrow for nearly all of the Sr^{90} atoms permanently lodged in the human body.

1. The decay constant (k) is inversely proportional to half-life (T 1/2), such that $K = \frac{0.693}{T\ 1/2}$.

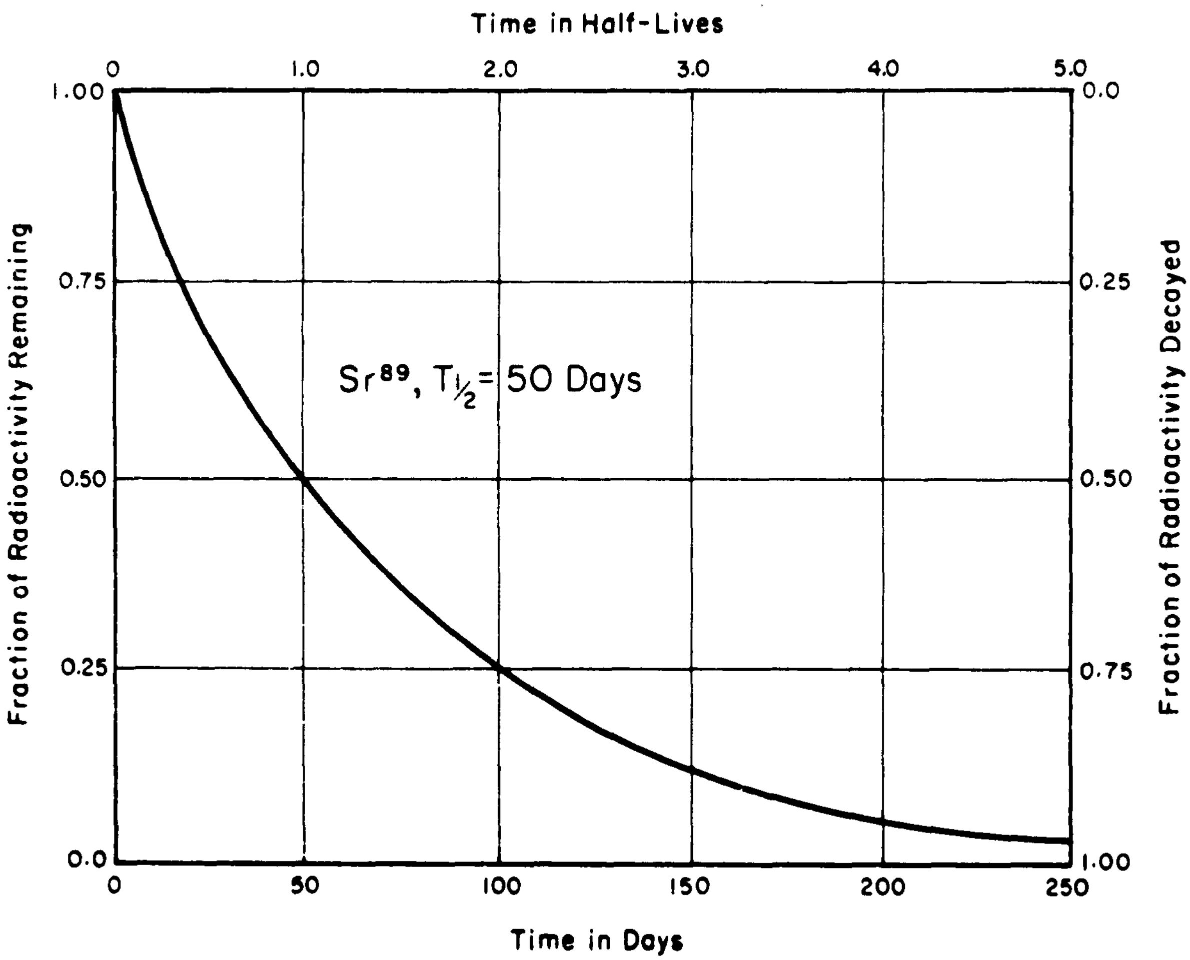


Figure 4.—THE MEANING OF HALF-LIFE

TABLE III - DECAY OF TYPICAL FISSION PRODUCTS

Isotope	Decay Scheme
Iodine-131	I^{131} $\xrightarrow{T_{\frac{1}{2}} = 8d}$ Xe^{131}; β (0.6-0.8 Mev); γ (0.4Mev)
Strontium-90	Sr^{90} $\xrightarrow{T_{\frac{1}{2}} = 27.7y}$ Y^{90} $\xrightarrow{T_{\frac{1}{2}} = 64.2h}$ Zr^{90}; β (0.54 Mev); β (2.26 Mev)
Cesium-137	Cs^{137} $\xrightarrow{T_{\frac{1}{2}} = 26.6y}$ Ba^{137m} $\xrightarrow{T_{\frac{1}{2}} = 2.6m}$ Ba^{137}; β (0.51 Mev); γ (0.66 Mev)
Barium-140	Ba^{140} $\xrightarrow{T_{\frac{1}{2}} = 12.8d}$ La^{140} $\xrightarrow{T_{\frac{1}{2}} = 40h}$ Ce^{140}; β (1.0 Mev); γ (0.03-0.54 Mev); γ (0.33-3.0 Mev)

Decay of Fission Product Mixtures

Mixtures of fission products, with each radioisotope species having a different half-life, do not decay according to the simple law illustrated in Figure 4. If the fission products remain thoroughly mixed, that is, if they are not selectively absorbed or precipitated by various interactions with soil or water, they decay according to the "1.2-law"[1] for the first six months following the fission explosion.

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1. $A_t = A_1 t^{-1.2}$ where A_1 and A_t are the radioactivities at one and t hours respectively, and t is the time elapsed in hours.

The "1.2-law" can be illustrated approximately as follows: for every 7-fold increase in time after the explosion, the radioactivity decreases by a factor of 10. Thus, if at one hour a water were contaminated with 1,000 μc of fission products per liter; at 7 hours, the contamination would be 1/10 x 1,000 or 100 μc/l; at 7 x 7 = 49 hours, the contamination would be $(1/10)^2$ x 1,000 or 10 μc/l; while after the passage of 7 x 7 x 7 = 273 hours, the concentration would be reduced to 1 μc/l.

HEALTH HAZARDS FROM RADIATION

Effect of Radiation on Matter

Alpha, beta, and gamma radiation are often termed "ionizing radiation" because they produce ions as they pass through matter. An ion is nothing more than an atom that has temporarily lost an electron and has become positively charged.

Gamma radiation is far more penetrating than alpha and beta, but has an identical physical effect (as distinguished from its biological effect) on matter. Gamma rays first act on the orbital electrons to force them out of their orbits at higher velocities. These electrons then act in a manner identical to beta rays, producing a series of ions along their paths. Gamma rays penetrate deeply into matter only because they react relatively infrequently with the orbital electrons.

Internal and External Radiation Hazards

During the early postattack period, external radiation is the primary problem and is due to the contamination of the land surface with fallout. In this situation, the radioactivity is external to the human body and penetrating gamma radiation is the main concern. Although water and food might be heavily contaminated during this period and their consumption would cause an internal radiation hazard, this would be relatively minor compared to the external radiation exposure resulting from gaining access to them. At such a time individuals would be required to take shelter to avoid the high external radiation hazard.

With the passage of time, the external hazard diminishes and the internal hazard becomes of greater relative concern. In this situation, radioisotopes are taken into the body by ingestion or inhalation and are retained, often finding their way to particular organs where they may remain for long periods, releasing their radiation energy by decay. As noted earlier, Sr^{90}, for example, is deposited in the bone and remains there more or less permanently. Iodine-131 (I^{131}) deposited on vegetation will be incorporated into the milk of grazing animals and ultimately into the human thyroid gland after consumption of the milk.

Control over internal radiation hazards is achieved by limiting the intake of radioactivity. In the case of water, the OCD is not making recommendation on drinking water standards after bomb detonation.

Radiation Dose - The Roentgen

Radiation dose is measured in units called the "roentgen". A careful distinction should be made between "radioactivity" measured in disintegrations per minute or in curies and the subsequent "radiation dose" resulting from the absorption of this radiation by matter. It is somewhat difficult to relate the roentgen directly to the curie, as the roentgen would depend on the energy and type of radiation released in the decay of the radioactivity and the location of the exposed individual with respect to the radioactive source. The curie depends only on the number of disintegrations per minute.

Two simple examples would serve to illustrate the dependence of the roentgen-curie relationship on the specific conditions of exposure. An individual located 10 feet from a one curie source of fission products would receive a radiation dose of approximately 0.04 roentgens in one hour. However, if the curie of fission products were taken internally the radiation dose at one hour after ingestion would be about 100 roentgen.

In the scientific and professional literature concerned with radiation protection, the rad (for radiation absorbed dose) has replaced the roentgen as a unit of radiation dose and the rem (roentgen equivalent man) is used to describe the equivalent biological dose from various types of radiation. However, for most of the problems we may encounter in protection from fallout, the three units are substantially equal. The difference between the roentgen and the rem become practically significant only in situations involving exposure to alpha radiation emitters.

Biological Effects of Radiation

Some exposure to radiation is unavoidable. Inside our bodies, there are small amounts of radioactivity that occur naturally (carbon-14, potassium -40, etc.) and continuously expose us to radiation internally. All soil and rocks contain some uranium, thorium, and radium and thus are a constant source of external exposure as well as internal. Radiation is employed to diagnose and treat disease and consequently this is another essentially unavoidable source of exposure. Finally, with the development and testing of nuclear weapons, all humans have been exposed to small internal and external radiation doses from world-wide fallout. From all of these sources, the average individual receives about 10 roentgens in a lifetime. It is generally agreed that this low-level exposure is acceptable and not likely to cause significant or measureable harm. In fact, probably much larger doses could be tolerated providing these were spread over periods of several weeks to several years, as there is ample evidence to show that the body recovers from small repeated radiation exposure.

When large amounts of radiation are absorbed by the body in short periods of time, sickness and death may result. Few people become seriously sick when exposed to 100 roentgens in a few days, whereas a majority of those receiving 600 roentgens would die. Exposure to 300 roentgens would cause radiation sickness in all exposed persons but death in only a fraction. These same doses, if received over a period of months, would probably cause no apparent effect as the body would have time to repair much of the cell damage as it occurs.

The effects of various short-term radiation exposures are summarized in Table IV.

TABLE IV

ACUTE EFFECTS OF SHORT-TERM RADIATION EXPOSURE

Radiation Dose Roentgens	Effect
50	Smallest dose detectable in an individual by laboratory methods.
75-100	May cause transient nausea on day of exposure in 10% of the people exposed.
200	Largest dose that does not cause illness severe enough to require medical care in the majority of people (90-95%).
450*	Will cause death to about 50% of the people exposed, 3 to 4 weeks after exposure.
600	Will cause death to almost everyone so exposed, 2 to 3 weeks after exposure.

* The "Median Lethal Dose" or LD-50

Management of Individual Radiation Dose

During the immediate postattack period, waterworks personnel will undoubtedly be called upon and expected to perform duties that will incur radiation exposure. Where these duties are vital to the community, they must be performed with the expectation that certain individuals will be exposed to excessive radiation doses and will develop the symptoms of radiation sickness. However, if the total radiation dose associated with the performance of certain essential tasks is spread among all of those capable of performing the task, acute radiation effects will be minimized. For example, if five individuals are capable of operating welding equipment and welding is needed requiring about one hour in a radiation field of 50 roentgen per hour (total dose of 50 roentgen), then if other circumstances make it practical, each welder might work only 12 minutes and receive only 10 roentgen.

The early symptoms of radiation sickness are delayed, perhaps a day or more, and it is therefore essential that waterworks personnel, especially those performing key operating functions, maintain individual records of radiation exposure during the postattack period. Only by having such records will it be possible to intelligently and equitably provide personnel for the performance of vital operating functions. As total radiation dose is the product of dose rate and time (that is, roentgen per hour x hours), frequent measurements of the dose rate is necessary when an individual is in or moving through a high radiation field. This is especially true early in the post-attack period when radiation dose rates are changing rapidly with time or when the fallout distribution is irregular with localized hot-spots.

MEASUREMENT OF RADIATION AND RADIOACTIVITY

Determination of Radiation Dose

In evaluating the effect of radiation on living things, we are concerned with the total exposure or "dose" and in the rate of exposure or "dose rate". As mentioned previously, the roentgen (or the rad or the rem) is the unit of measurement of radiation dose; and dose rate is usually expressed in roentgens per hour (r/hr). The roentgen applies to all radiation exposure situations -- both external and internal. Instruments are available that may be placed in a radiation field, that is near a source of radiation, and will read either dose rate or accumulated dose. These instruments are termed "survey meters" and "dosimeters", respectively. The survey meter scale is generally calibrated in roentgen per hour (r/hr) or milliroentgen per hour (mr/hr), but may occasionally be designated in counts per minute (cpm), rad/hr, or rem/hr. An instrument responding in this way to radiation is also termed a "rate meter". The dosimeter scale is calibrated in either roentgen or rad.

Civil Defense Radiological Instruments

The Office of Civil Defense has developed several radiological instruments which together provide a wide monitoring capability. All of these instruments are designed to detect and measure gamma radiation and certain of them have the additional capability of detecting beta radiation. Four of these instruments are illustrated in Figure 5.

The CD V-700 (0-50 mr/hr) survey meter can be used to measure gamma dose rates and to detect the presence of beta emitting radioisotopes. It is intended for use in training decontamination operations, for personnel monitoring, and for indicating the extent of radioactivity contamination of food and water. Because of its limited scale range, this instrument is intended for low-level measurements and has limited usefulness in areas of high contamination. The detector is provided with a removable shield. With the shield in place, the instrument reads the gamma dose rate in mr/hr. With

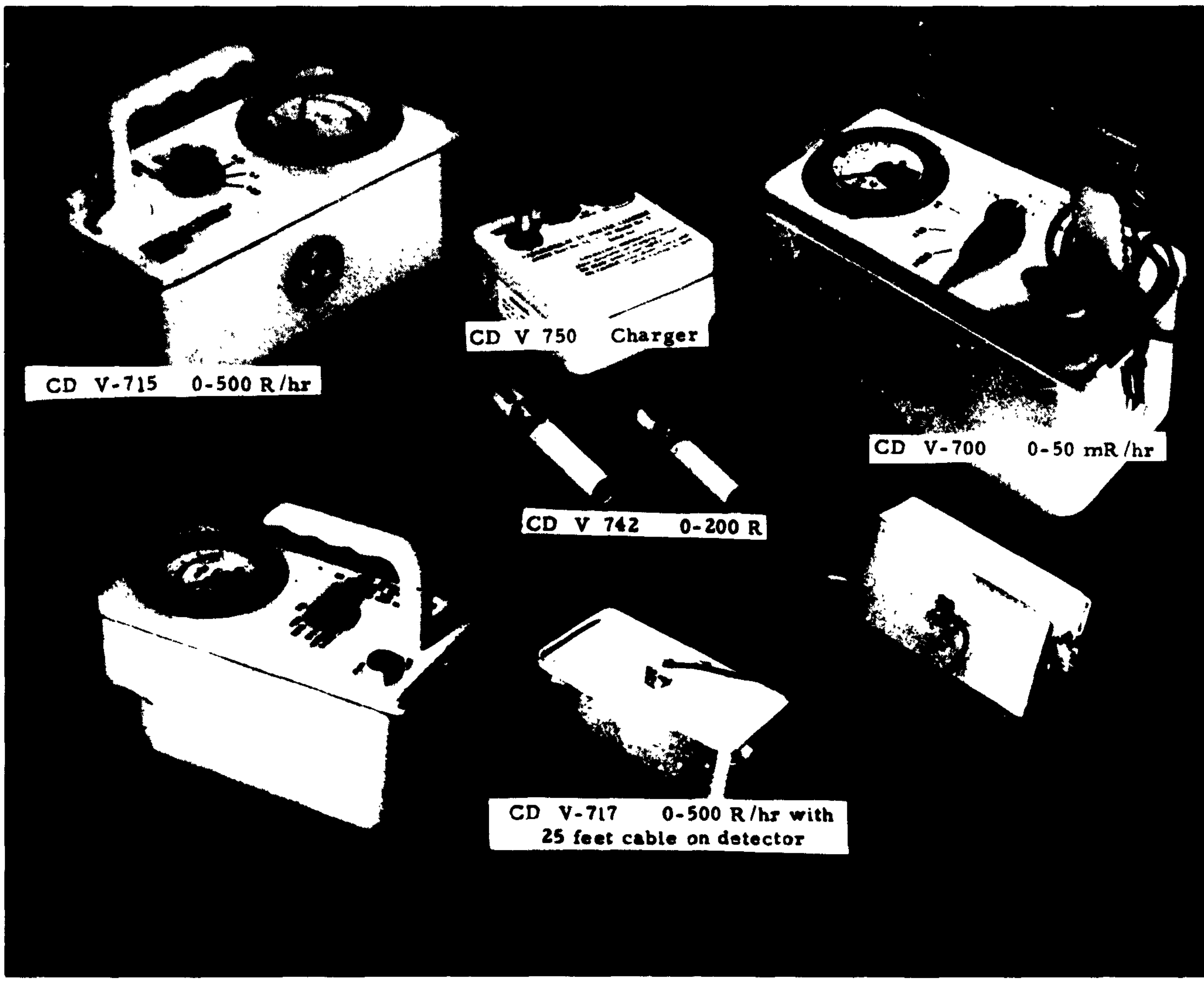

Figure 5.— CIVIL DEFENSE RADIOLOGICAL INSTRUMENTS

the shield removed, the instrument is sensitive to both gamma and beta radiation.

The CD V-715 (0-500 r/hr) survey meter will measure gamma radiation dose rates only and is the basic instrument for general postattack monitoring. It can be used for ground surveys, for monitoring in and near community shelters, and as an interim aerial survey instrument. This instrument has no beta detection capability. A modification of the CD V-715 is available and is designated the CD V-717. This modification allows the detector to be removed from the instrument case and placed up to twenty feet from the indicating scale. It is useful in monitoring an exposed or contaminated area from a shelter.

The CD V-742 (0-200 r) dosimeter is designed to measure the accumulated exposure doses of gamma radiation to operations personnel and shelter occupants. It would be especially useful to waterworks crews making emergency repairs to key elements of the distribution system. The instrument is carried in a shirt or coat pocket and is read by simply pointing it toward a light source and observing the position of a hairline on the internal scale. The instrument is first charged (with a CD V-750 dosimeter charger) such that it reads zero. Subsequent exposure to gamma radiation causes the instrument to discharge and the hairline to move. The maximum reading is 200 r.

Emergency Measurements of Radioactivity in Water

If the water supply system has ground water sources available, the operator need not be concerned with the measurement radioactive fallout contamination. However, if the system depends upon surface supplies only, the operator may be faced with determining the best time to utilize various portions of the supply. This decision depends upon monitoring data and the ability to switch from one supply to another, or adjust the depth that the water is withdrawn from a reservoir.

The determination of the amount of fallout in the plant or reservoir can be based upon radiation intensity meter reading. If they are then specific details should be given as to exact location of reading, height of meter held above ground, time after detonation, location used for "zeroing in" the meter, etc.

Even though the immediate "short term" internal hazard is deemed negligible, environmental measurements of the radioactivity levels should be continued postattack to provide the bases for ultimate long-term estimations of the effects, and to develop a better understanding of the postattack environment.

Monitoring of the water supply postattack with the available instrument will give valuable information as to the general levels of contamination and degree of hazard present.

Water utility personnel should be aware that the internal radiation hazard resulting from a nuclear attack is of importance only to those who survive the catastrophe. The ingestion of contaminated water is not among the hazards that will kill the population or cause a large number of radiation casualties. As a primary annihilator, contaminated water is of no consequence, because the external dose concomitant with a lethal internal dose is more deadly by several hundred times. The utilities must protect their staffs and operators from external fallout gamma radiation because of the top priority requirements for water in the postattack emergency period.

Monitoring Systems -- National and Local

The radiological defense information necessary to support postattack civil defense operations has required the establishment of a nationwide network of fallout monitoring stations. In addition to these, each group or public shelter should have the capability to perform monitoring, both for the safety of the shelter occupants and for the control of recovery and rehabilitation operations in contaminated areas adjacent to the shelter. A group shelter should be established in or near key waterworks facilities, such that both waterworks personnel and their families may be protected from fallout. The shelter would serve as a base for recovery work on the water system as well as a radiological monitoring station for the surrounding area. It should also provide those monitoring services necessary to assure water of acceptable radiological quality.

RADIOLOGICAL COUNTERMEASURES

From the standpoint of the water utility, a system of radiological countermeasures should be designed to protect waterworks personnel so as to insure the uninterrupted operation of the utility and to protect the consumer from unacceptable contamination of his drinking water. To meet the former objective, we are concerned primarily with external radiation exposure hazards to operating personnel; while in satisfying the latter, our concern is for minimizing the internal exposure of the consuming population. The countermeasures required to meet these objectives are inter-related and have a bearing on the overall problem of postattack recovery including those of fire control and the prevention of enteric disease. For example, if fallout contamination of key installations produces such high radiation fields that their return to operation is delayed or not possible, the interruption in water supply may result in further casualties and property damage due to fire. Moreover, a prolonged disruption of service may require the population to use contaminated water and lead to epidemics of waterborne disease.

When all factors are considered, it will probably be true that maintaining a water utility in operation and supplying adequate quantities of water of reasonably high bacteriological purity will have a greater influence in reducing casualties than if the supply were withheld from the consumer because of doubts regarding its radiological purity. In other words, water itself is such a great benefit that it overshadows the detriments that it may carry. This is because the radiocontaminants in water in a postattack situation are not likely to cause acute effects whereas the absence of water probably would.

Countermeasures to Insure Utility Recovery

The measures to be taken to insure the prompt postattack recovery of a water utility fall into four categories: 1) dispersal of facilities, 2) shielding, 3) decontamination, and 4) limiting exposure time.

Facility dispersal and the incorporation of shielding into installations requiring the services of personnel are measures that should be considered in the design of waterworks or in their modification or extension. Such measures are costly and, of course, must be completed before an attack to serve any purpose. Dispersal insures that not all of the system will become inoperative, either because of blast damage or fallout contamination with resulting high radiation fields. Shielding is often provided in the normal design of filter plants and pumping stations; while in many situations, the shielding capabilities of a structure can be further enhanced simply by giving this function some consideration during design. Two feet of concrete or three feet of earth are generally adequate and, of course, several feet of water provide an excellent shield. By providing multiple shelters, each located in an installation requiring personnel for operation, the advantages of shelter dispersal are achieved such that protection is quickly available before an attack, and time out-of-shelter is reduced in performing essential operating functions in the postattack period. In providing and equipping shelters, it is well to consider their adequacy for the families of operating personnel and, in some instances, whether they can also serve as community or neighborhood shelters.

Decontamination and limiting exposure time are important elements of the postattack countermeasure program. Natural decontamination is brought about by the passage of time due to the decay of fallout (i.e., the "1.2 law") and by the cleansing action of rainfall, the latter washing the fallout particles from smooth surfaces and transporting them short distances into the soil where earth shielding serves to reduce the air dose rate. In conducting artificial decontamination operations, a balance must be made between the exposure to personnel carrying out decontamination and the subsequent exposure to personnel carrying out functions in the decontaminated area. These considerations, together with the natural reduction in contamination with time, will limit artificial decontamination to restricted areas where occupancy is required for the operation or repair of vital equipment.

Washing with water is probably the most satisfactory means of decontamination. Although detergents and scrubbing brushes will lead to better removal of fallout, it is doubtful whether, under the circumstances extant in the postattack period, such adjuncts will contribute significantly beyond the decontamination efficiency possible with an ordinary fire hose.

Countermeasures to Reduce Drinking Water Contamination

The removal of radionuclides from drinking water has been the subject of much research and a considerable reference literature is available. What measures a water utility may practically take depends on its source of water, the location and nature of its storage and treatment facilities, and on the composition of the raw water. Since the major concern is for the removal of particulate matter (although the strontium and cesium isotopes may also appear in solution), the clarification units should be operated at peak efficiency.

Well waters will be free of contamination and will require no special treatment. Surface waters may be handled in a wide variety of ways. Impounding reservoirs may be used for storage (and radioactive decay) and for sedimentation. Rapid sand filter plants with coagulation and sedimentation may be simply operated so as to remove a maximum of suspended matter. Softening or demineralization plants should be operated to remove a maximum of suspended solids as well as hardness, the removal of the latter serving to also remove the chemically similar Sr^{89} and Sr^{90}. Ion exchange systems are by far the most efficient and can be expected to reduce contamination to 0.1 percent of its raw water concentration.

During the early phases of the postattack period, external radiation hazards will be by far more critical than internal radiation; but over periods of months and years, after the passage of the acute emergency, the internal hazards from water and food may become relatively more significant. Fortunately, the delayed aspects of the internal hazard problem provide the time to find specific solutions as the problems are identified.

REFERENCES ON NUCLEAR ENERGY AND FALLOUT

Glasstone, S., Sourcebook on Atomic Energy. D. Van Nostrand Co., 1957

The Effects of Nuclear Weapons. Department of the Army Pamphlet No. 39-3, April, 1962.

Eisenbud, M., Environmental Radioactivity. McGraw-Hill Book Co., Inc., 1963.

Personal and Family Survival. Civil Defense Adult Education Course Student Manual, SM 3-11 (Revised) May, 1963. Office of Civil Defense, Department of Defense.

Handbook for Radiological Monitors. Office of Civil Defense, Department of Defense, FG-E-5.9, April, 1963.

Exposure to Radiation in an Emergency. National Committee on Radiation Protection and Measurements, Department of Pharmacology, University of Chicago, Report No. 29, January, 1962.

Owen, W. L., Radiological Protective Construction, U. S. Naval Radiological Defense Laboratory, USNRDL-467, January 8, 1962.

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