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Prepared by

SAFETY OFFICE

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RADIOLOGICAL

SAFETY

HANDBOOK

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JOHN F. KENNEDY SPACE CENTER, NASA

November 1, 1964

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INTRODUCTION

PURPOSE

This handbook describes the organization, policy, procedures, and safety requirements for the radiological safety (RADSAFE) program of the John F. Kennedy Space Center (KSC). It is written as a technical supplement to Safety Regulations, TSOP's, and Safety Plans for users of X-rays and radioactive materials. The handbook distinguishes between real and imagined dangers of radiation, and should replace unwarranted fears with respect and understanding.

SCOPE

To fulfill the purpose stated above, this handbook specifically defines KSC procedures and requirements for:

a. Procurement, transfer, and shipment of radioactive materials.
b. Handling and disposal of radioactive materials.
c. Personnel monitoring, doses, and emergency procedures.

For more detailed information on a particular subject, refer to the bibliography of this handbook.

RESPONSIBILITY

The supervisors directly concerned with radioactive material will implement the requirements and procedures as outlined in Safety Regulations and detailed in this document. However, each individual who might be exposed to ionizing radiation must also be familiar with the established Safety Regulations and procedures. In addition, the biological effects and the importance of personal hygiene should be familiar subjects to all concerned.

POLICY

It is the policy of KSC to expose personnel to ionizing radiation as little as possible, and to ensure that all its RADSAFE procedures and policies comply with the regulations set forth by the Atomic Energy Commission and other cognizant federal and state agencies. This handbook does not replace these pertinent regulations. Rather, it refers to them where applicable, and contains discussions and delineations of the conditions most often encountered. It is the responsibility of all personnel to acquaint themselves fully with the provisions of those regulations that pertain to their duties.

CHANGES AND REVISIONS

The information in this manual is compatible with the latest technological findings concerning the use, effects, and handling of ionizing radiation. Continuing investigation, however, of the problems of radiation hazards, may make this handbook subject to revision or change. As new radiation-hazard information develops, this handbook will be revised to incorporate it. A Change will consist of one or more new pages containing updated material. A new title page for the handbook will be included with each change, showing the latest effective date. These Changes will be distributed by the Safety Office (S) to all persons issued a copy of the basic handbook. When a Change is received, insert the new pages in their proper location in the handbook; remove and destroy any superseded pages. Each person holding a copy of the basic handbook is responsible for keeping his copy up to date.

Each page containing changed material will have the word "Changed", followed by the change date, at the bottom of the page opposite the page number. A change in the technical content of a text page will be indicated by a vertical black line in the outer margin of the page, extending the full depth of the changed text.

A List of Effective Pages ("A" page) at the front of each handbook lists all the pages in the handbook. A new List of Effective Pages will be issued with every change, listing every page in the handbook, with the date of the last change, and indicating the pages included in the current change. A cross-check on the status of the handbook can be made by referring to the latest List of Effective Pages.

Whenever the number of pages affected by previous Changes, plus the pages affected by the current Change, total over 60 percent of the handbook, a Revision will be issued. A Revision is a complete reissue of the handbook, with all change dates and symbols deleted, and all modified page, figure, paragraph, and table numbers renumbered in sequence. When a Revision is distributed to holders of copies of the handbook, they should remove from the binders all previous pages of the handbook, insert the Revision pages in the binder, and destroy the old pages.

COMMENTS AND SUGGESTIONS

Comments and suggestions from users of this handbook are welcomed and encouraged. It is hoped that all persons engaged in work involving radioactivity and radiation will be continuously safety-conscious. A safety-conscious work force will undoubtedly observe conditions and practices which should be included in this handbook. Constructive criticism will improve its usefulness.

Comment sheets will be found at the back of the handbook. Fill out one or more of these sheets, describing your suggestion as completely as possible. Give your name, location, and organization so you may be contacted for additional information. Take, or mail, the comment sheet to the Safety Office (S). All comments, suggestions, and criticisms will be given the fullest consideration, and will be incorporated into the handbook when deemed practical by the Safety Office.

SECTION I

IONIZING RADIATION

1-1. DESCRIPTION

Radiation falls into two categories: ionizing and nonionizing. The term "ionizing radiation" is applied to any electromagnetic or particulate radiation containing sufficient energy to produce ions, directly or indirectly, in the material through which it passes. The subject of this handbook is ionizing radiation and its applicable safety requirements. Therefore, in the following material "radiation" will always mean ionizing radiation unless otherwise stated.

1-2. RADIOACTIVITY

Much has been written about radiation and its deleterious effects upon living matter, but many misconceptions about it remain. Man has been exposed to nuclear radiation in varying amounts since he appeared on earth. In addition, long before man appeared, the earth was being subjected to nuclear radiation as regularly as it received light from the sun. However, only since the beginning of this century have scientists come to understand the nature and potential for nuclear radiation. With this new knowledge have come increased uses of radiation, along with the attendant exposure hazards.

The subject of radiation is far too complex to be covered adequately in a handbook of this nature. Still, an understanding of radiation and its effects is possible without an extremely technical background. Therefore, this section contains the information necessary to provide an understanding of the technical terms and exposure criteria found in the following sections.

1-3. ATOMIC STRUCTURE

The atom is the smallest particle of an element which retains the characteristics of an element. It consists of a positively charged nucleus and one or more negatively charged electrons. Ordinarily, these positive and negative charges are balanced, and the atom is electrically neutral.

The nucleus contains practically all the mass of the atom. Basically, the nucleus consists of individual particles of matter called protons and neutrons. The protons are positively charged and the neutrons are electrically neutral.

For each positively charged proton in the nucleus, there is a negatively charged electron in orbit around the nucleus of a neutral atom. The number of electrons in the orbital paths (rings) of an atom is, therefore, determined by the number of protons in the nucleus. The nature of the element (whether the element is iron, hydrogen, mercury, etc.) is determined by the number of protons in the nucleus. The number of protons in elements ranges from one (Hydrogen) to 103 (Lawrencium). Each time the number of nuclear protons is changed, a different element results.

The number of neutrons, however, may range from none to 150. Most elements as found in nature are mixtures of several different atoms, each having the characteristic number of protons typical of the element, but having different numbers of neutrons. Chemically, these elements are the same since chemical reactions depend on the number of electrons only. The number of the neutrons in the atom does not alter its chemical characteristics. However the number of neutrons does affect the atomic weight which, for the purpose of this discussion, is the sum of the protons and neutrons. The atomic number of an element is the number of protons in an atom of that element. Thus, atoms of the same element are the same chemically, but may vary in their atomic weight. These differing atoms of the same element are called isotopes. Some isotopes are unstable, that is radioactive, while other isotopes are stable and not radioactive.

1-4. ISOTOPES

Figure 1-1 shows various natural isotopes of hydrogen. The heavy isotopes of hydrogen constitute only a small fraction of one percent of the total hydrogen found in nature. Note in the deuterium atom that the nucleus consists of one proton and one neutron to give an atomic weight of two. Likewise, in the tritium atom the nucleus consists of one proton and two neutrons. If some water is made in which deuterium instead of the normal isotope of hydrogen is used, it will look, taste, and feel like water which, chemically, it is. However, from a nuclear viewpoint, it differs from ordinary water in atomic weight and is called heavy water.

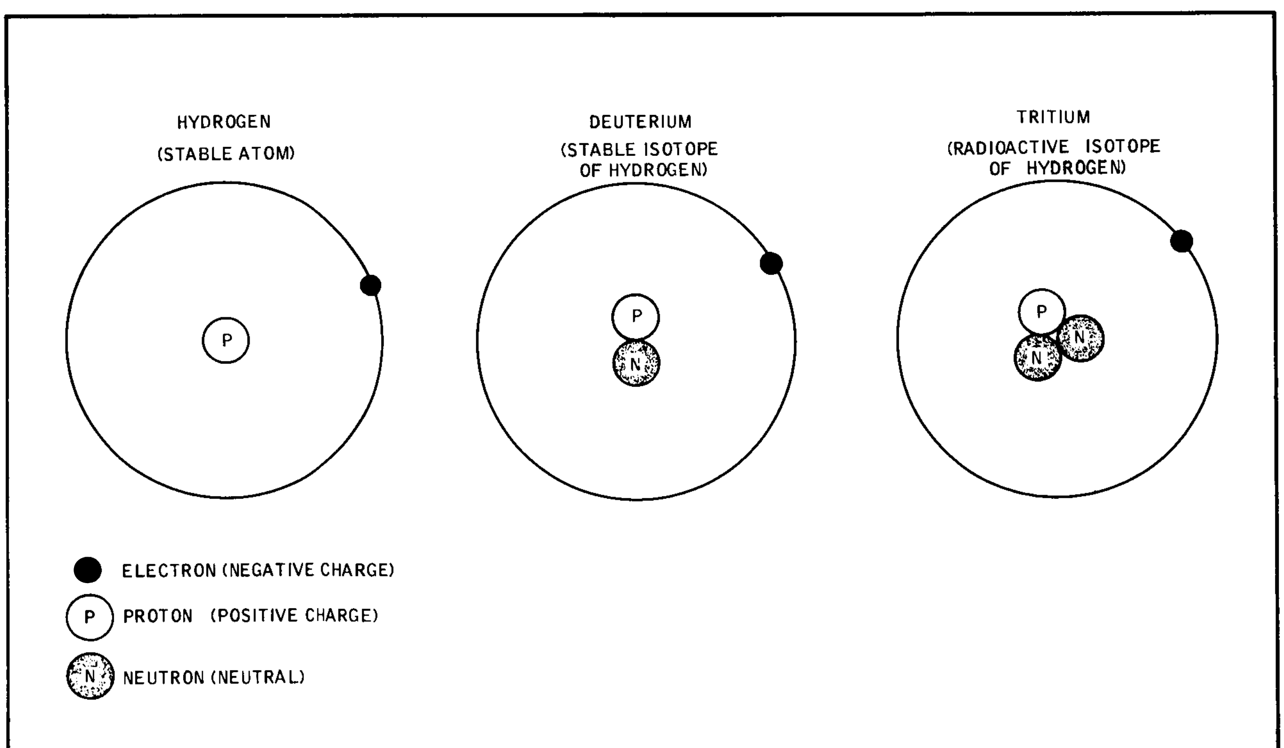


Figure 1-1. Isotopes of Hydrogen

Two different isotopes of uranium are uranium 238 and uranium 235. Chemically, a mass composed of either or both of those two isotopes is uranium. However, the nuclear difference is significant. Not only is the isotope U235 radioactive, but it is also fissionable, a characteristic which will be discussed later.

1-5. PARTICLES AND RAYS

About half the naturally occurring chemical elements contain radioactive isotopes. These radioisotopes are not stable; they undergo a spontaneous nuclear change until they decay into a stable isotope. This change causes three major kinds of radiant energy to be emitted from the nucleus: alpha, beta, and gamma. Alpha and beta radiations are particles of the radioactive atom. Streams of these particles are sometimes called alpha and beta rays. The gamma ray is an electromagnetic wave similar to X-rays. Each atom of radioactive material emits one or more of these radiations, in a fixed pattern uniquely characteristic of that particular element. While emitting these radiations, the element decays or disintegrates into another element or isotope. The time required for half the atoms of a given amount of any radioactive isotope to decay into a stable isotope is called its half-life (figure 1-2). Such half-lives range from fractions of a second to billions of years. For example, the half-life of radium is 1600 years. That is, if one ounce of radium were set aside, 1600 years later it would be 1/2 ounce of radium and 1/2 ounce of stable lead. After another 1600 years, the remaining 1/2

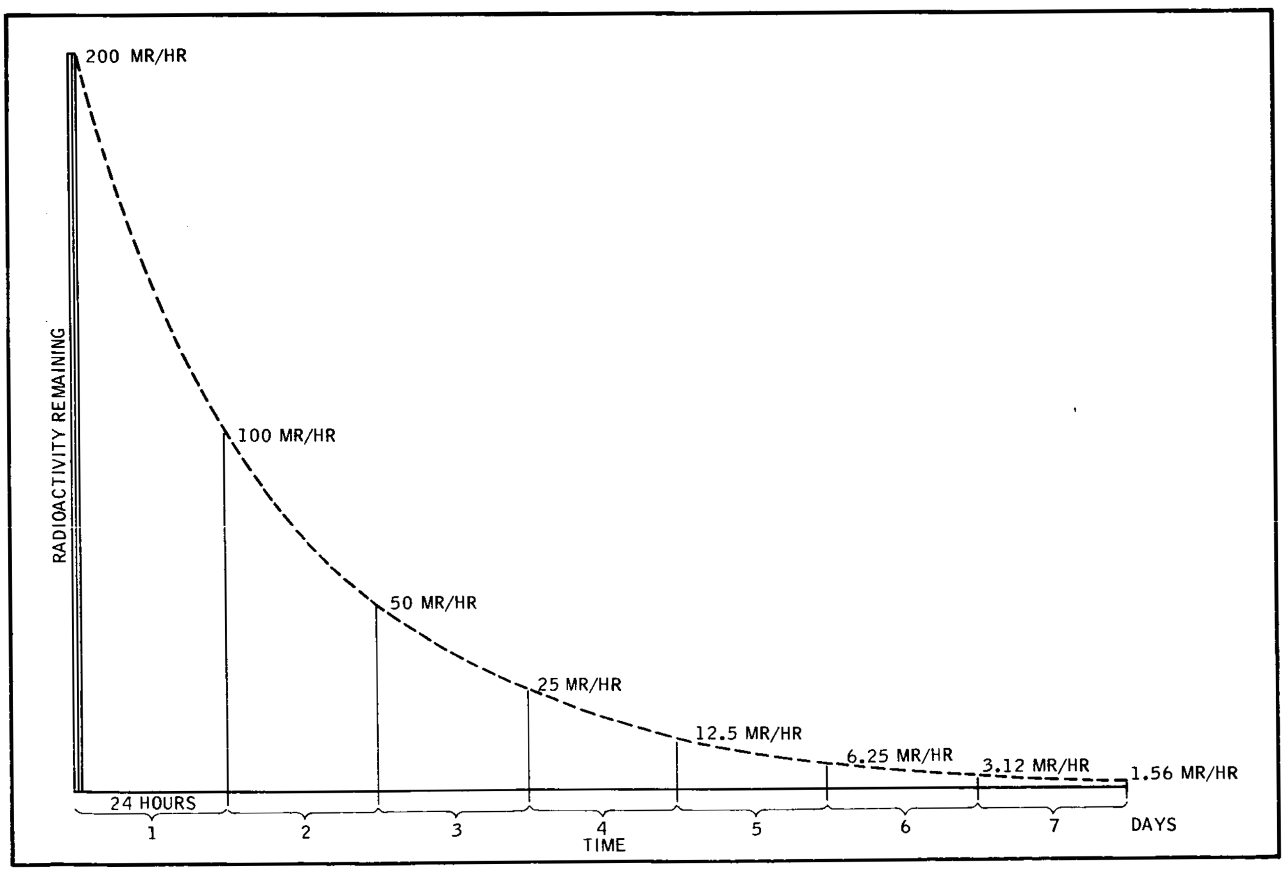


Figure 1-2. Decay of a Radioactive Material with a 24 Hour Half-Life

ounce of radium would have decayed into 1/4 ounce of radium and 1/4 ounce of lead. This process would continue until all the radium had become lead. Elements that emit nuclear radiation spontaneously are naturally radioactive. However, some stable elements can be converted into radioactive elements. These artificially radioactive elements are known as radioisotopes. Radium is a natural radioactive element while cobalt is not. However, if cobalt is submitted to neutron bombardment in a nuclear reactor, it becomes a radioisotope of cobalt.

Two important characteristics of radioactive material are:

a. Material cannot be made radioactive by being submitted to alpha, beta, or gamma radiation, nor does it become radioactive when it is contaminated with a radioactive material. To make a material radioactive, it must be submitted to neutron bombardment.

b. The rate of spontaneous release of nuclear radiation from the atom occurs naturally and cannot be increased or decreased by any known means. Consequently, the radioactivity cannot be removed from a radioactive material. However, there are means available to protect personnel from the harmful effects of radiation, which will be covered in the following sections.

1-6. Alpha Radiation. Alpha particles compose the nonpenetrating form of external radiation. An alpha particle is a piece of the nucleus of the radioactive element. Alpha particles are the same as helium nuclei; i.e., two neutrons and two protons stripped of their orbiting electrons. The alpha particle cannot penetrate even the outer layer of dead skin; therefore, it does not present an external radiation hazard.

1-7. Beta Radiation. The beta particle, an electron ejected at high speed form the radioactive nucleus, is one of the two penetrating forms of radiation. However, it is the less penetrating form. Beta rays have relatively short ranges in air, generally not more than a few feet, but material within range would be subjected to the effects of beta radiation.

1-8. Gamma Radiation. Gamma radiation is the most penetrating form. It is an electromagnetic ray similar to X-rays but somewhat more penetrating. Gamma radiation originates when the discharge of alpha and/or beta particles does not remove sufficient energy from the radioactive nucleus for it to become stable. If the particle leaving the atom does not take with it all the energy the atom is trying to get rid of, the atom will throw off the energy in the form of gamma radiation.

1-9. ATOMIC DECAY

As stated previously, the radioactive atom decays, or disintegrates, by emitting alpha and beta particles through its successive disintegrations until it becomes a stable atom. When it becomes stable, no further radioactivity is possible from the atom. However, all the atoms do not decay simultaneously, but rather in succession, as evidenced by the half-life levels.

Consider, for example, an atom in a given quantity of uranium 238, the atoms of which contain 92 protons and 146 neutrons in the nuclei. Typically, decay begins when the U238 atom emits an alpha particle. An alpha particle consists of two protons and two neutrons. With the alpha particle thrown out, 90 protons and 144 neutrons are left in the original U238 atom. But it is no longer an atom of uranium. It is now an atom of thorium 234, a daughter product of uranium 238 and a beta emitter.

The thorium atom ejects an electron from one of its neutrons. With the loss of an electron, the neutron becomes a proton and the atom now has not lost a neutron but gained a proton. This changes the atom from thorium to protoactinium 234, with 91 protons and 143 neutrons.

Table 1-1 shows that through successive emissions of alpha and beta particles the U238 atom eventually decays into an atom of lead 206. However, all the uranium atoms are not decaying at the same rate. Thus, as the decay process goes on, some of the transient elements emit alpha and beta particles and some gamma radiation. This explains why radium is a gamma and beta emitter. Pure elemental radium, freshly prepared, in an alpha emitter and, therefore, could be handled with the bare hands so far as external hazards are concerned. (Of course, in reality neither radium nor any other radioactive material is unnecessarily handled with bare hands.) However, the radium begins to decay immediately into daughter products. Therefore, alpha, beta, and gamma radiation are all given off from the radium and its daughter products.

1-10. USES OF RADIOACTIVE MATERIALS

Certain hazards are inherent in radioactive materials; however, the properties that make the material hazardous are beneficial when properly and safely applied. The important properties of radioactive material in this handbook are radiation, ionization of air, destruction of living cells, excitation of atoms in other material, and electrical current production. All of the beneficial applications of radiation are too numerous to be mentioned in a handbook. Nevertheless, some uses are mentioned to clarify controversial points. For instance, a great deal of confusion exists between the diagnostic and therapeutic uses of radioisotopes. Radioisotopes may be used solely to discover the nature of an illness or disease. They may also be used to treat or cure the illness. In some instances, as soon as a patient learns that radioisotopes are involved, he concludes that he has cancer. This may be because the use of radiation in the treatment of cancer is widely known. Somewhat less well known is its use as an indicator or tracer of biological processes.

1-11. RADIATION

Radioisotopes characteristically emit signals which can be detected electrically or chemically. This use, alone, makes them extremely beneficial to mankind. For instance, in therapeutics it is possible to trace accurately the biological processes in man, animal, and plants. As an example, the thyroid gland is very important to the human body. It is medically accepted that the thyroid gland will absorb practically all the iodine that en-

Table 1-1. Decay of a Uranium Atom

Element & Atomic Wt.	Type of Radiation Emitted	Number of	
		Protons	Neutrons
Uranium 238	Alpha particle	92 -2	146 -2
Thorium 234	Beta particle	90 +1	144 -1
Protactinium 234	Beta particle	91 +1	143 -1
Uranium 234	Alpha particle	92 -2	142 -2
Thorium 230	Alpha particle	90 -2	140 -2
Radium 226	Alpha particle	88 -2	138 -2
Radon 222	Alpha particle	86 -2	136 -2
Polonium 218	Alpha particle	84 -2	134 -2
Lead 214	Beta particle	82 +1	132 -1
Bismuth 214	Beta particle	83 +1	131 -1
Polonium 214	Alpha particle	84 -2	130 -2
Lead 210	Beta particle	82 +1	128 -1
Bismuth 210	Beta particle	83 +1	127 -1
Polonium 210	Alpha particle	84 -2	126 -2
Lead 206	NONE (Stable Isotope)	82	124

ters the body. If a certain amount of radioactive iodine is injected into the body, it is still iodine chemically and therefore, will go to the thyroid gland if it is functioning properly. The surgeon can determine, by using electrical counters, whether the thyroid is functioning properly by comparing the radioactivity recorded in the thyroid with what it should be. In this case, the radioactive iodine is doing nothing for the patient or for his thyroid condition. The iodine is merely indicating the functional state of the gland. There are many other uses of radioisotopes as tracers in medicine, and new uses are being discovered every day.

One of the world's most pressing problems today is the explosive growth of population and the necessity for feeding more people every year. The application of scientific principles to overall food production is still practically in the experimental stages. Much of the nutritive feeding of animals and plants intended for human consumption is done at random. Using radioactive tracers, scientific knowledge can replace some of the guesswork thus increasing the yield of food. As a typical example, the use of calcium and phosphorous tracers has provided information which will enable livestock feeders to get maxium efficiency from feed. This information permits better control of the calcium-phosphorous ratio of the diet, and elimination of elements which adversely affect the absorption of these elements.

As the biological processes in man and plants can be traced, so can the physical processes of machinery. This is done by making some of the material radioactive, or by including some radioactive material similar to the material to be traced. A simple example of this is the use of a radioisotope of iron to check engine wear. The piston rings are made of radioactive iron. As the piston ring wears, the radioactive iron is carried into the engine lubricating oil by the normal operation of the lubrication system. The level of radioactivity in a test sample of the oil indicates piston ring wear.

Another beneficial use of the radiating properties of isotopes is radiography, or material density tests. Some piping, for instance, must be built to withstand very high pressures. To insure uniform tensile strength of the weld seam, radioactive cobalt is inserted into the pipe line at the weld. The weld seam is then surrounded by X-ray film. The amount of radiation coming through the weld seam is inversely proportional to the density of the seam. Radiation escaping in flaw areas such as air pockets or slag deposits within the seam will expose the film more than in the areas of desired density. When the film is developed, the flaw areas of the weld will appear darker.

1-12. IONIZATION OF AIR

Another useful characteristic of radioisotopes is making the air electrically conductive. The accumulation of static electricity on machinery and equipment is a serious hazard in areas where explosive vapors may exist. The machines and equipment could be grounded or surrounded by a humid atmosphere, but these provisions are not always practicable or satisfactory. The use of radioactive static eliminators is more convenient. The radiation field from the isotope within the static eliminator ionizes the air and thus provides a nonmechanical ground path for the static electricity.

1-13. CELL DESTRUCTION

A very important characteristic of radioisotopes is that they emit energy that can actually destroy living tissue. This is the property that creates the greatest hazard in the use radioactive materials. However, for the moment, only the beneficial effects will be considered; the hazardous effects will be covered in a separate section.

Radiation therapy in the treatment of malignant growths is well known today. The ability of radiation to kill living cells is the basis of this therapy. Periodic exposures to radiation will retard, and in some cases arrest the spread of a malignant growth. Despite its therapeutic value, radiation must be administered and controlled by competent medical personnel. Otherwise, the treatment may easily result in organic damage to the patient.

Another use of radiation from radioisotopes is in the sterilization of food and drugs. The food or drugs are sealed in moistureproof containers to prevent contamination from the outside air. The containers are then subjected to doses of radiation so that any living organisms in the food or drug are killed.

If all the organisms are killed, the food is sterilized. If a lesser dose is administered, the food is pasteurized. That is, not all the organisms have been killed, but enough have been killed so that the food can be stored for a reasonable time without suffering destruction by bacteria. It should be noted here that the food is not radioactive any more than a person is radioactive after having an X-ray examination. In the radiation process applied to drugs, the radiation sterilizes the drug by killing the bacteria. The radiation does this without raising the temperature of the drug; consequently it is not damaged.

1-14. EXCITATION OF ATOMS

Another property of radioactive material that can be exploited is that the radiation energy can be used to excite the atoms of other materials. Radium dial watches are good examples. Contrary to popular belief, it is not the radium in the dial that glows in the dark, but the phosphor, such as zinc sulfide, which is excited by the radiation. It is the nature of a phosphor to emit light when influenced by radiation. Other examples can be found in the chemical industry and the manufacture of synthetic materials. Here, the energy of radiation is used to remove some of the atoms or to rearrange the molecular structure of the material thus altering the physical characteristics of the material.

1-15. ELECTRICAL CURRENT PRODUCTION

The energy of radioactive material also produces electrical current. This is a direct production of electricity from the energy released by the radioactive atoms. This is not the same as electrical current indirectly produced in power reactors, where the fission energy is converted to heat and then to electricity. Although the quantity of current is extremely small, batteries of radioactive material, or atomic batteries, are dependable sources of electrical energy where small quantities of current are required.

1-16. FISSIONABLE MATERIAL

The natural decay of radioactive material emits energy that can be used creatively in many ways. However, this energy is released at too low a rate to substitute for conventional sources such as coal and oil. For large quantities of energy from radioactive material, atomic fission must be exploited.

The fact that a material is radioactive does not necessarily mean that it is fissionable. Only a few radioactive materials are fissionable; most of the radioisotopes used in laboratories and commercial applications are not. In fissionable material, the nuclei split when struck by a neutron traveling at the proper speed. When the nucleus splits, part of its mass is converted to energy. At the same time, some neutrons and radiation are released, and two smaller atoms are formed. Only two readily available materials have these properties. One is uranium 235, an isotope of uranium found in uranium 238; the other is plutonium. Plutonium is not a natural element; it is created from uranium in nuclear reactors.

The amount of uranium 235 in uranium 238 is less than one percent. To obtain appreciable quantities of U235, some of the atoms of U238 must be removed. This is accomplished by a very complicated process called gaseous diffusion. Removing the U238 increases the proportion of U235; the resultant material is enriched uranium. The degree of enrichment is expressed as a percentage. Normal uranium is about 0.7 percent enriched. If gaseous diffusion removes enough U238 atoms so that 10 percent of the resultant mass is U235, then the material is 10 percent enriched uranium.

1-17. CRITICAL MASS

Figure 1-3 shows graphically what happens when a neutron strikes a nucleus of a fissionable material such as enriched uranium or plutonium and initiates a chain reaction. The atom splits, energy is released, two smaller atoms are formed, and one to three neutrons are liberated to continue the fission process.

Some of the atoms in fissionable material are spontaneously fissioning all the time. Therefore, a spontaneous chain reaction can occur if enough fissionable material (enriched uranium, for example) is assembled into the proper configuration. The quantity of fissionable material which will provide a self-sustaining chain reaction is known as the critical mass of that material. Figure 1-4 illustrates, step by step, a hypothetical example of what happens when a critical mass is assembled piece by piece.

In step 1, the black dots represent U235 nuclei; the electrons are not concerned in the fission process. In step 2, one atom has spontaneously fissioned, throwing out neutrons which start a chain reaction. Though uranium is dense, it is still mostly space, and neutrons can easily escape from the mass into the surrounding air. Most of them do; therefore, these intermittent little chain reactions do not multiply and sustain themselves.

Adding (in step 3) another subcritical mass of fissionable material to the first one, the mass and area of the material is increased. Now some neutrons escape from the first mass and strike nuclei in the second mass, causing additional fissions (step 4). However, the surface-to-mass ratio is still so large that a self-sustaining chain reaction cannot occur. More neutrons are being lost through the surface area than are causing additional fissions.

In step 5, a third piece of fissionable material is added to the mass, further reducing the surface-to-mass ratio. The chain reaction starts and the neutrons begin to multiply, as shown in step 6. There is now insufficient surface area, compared to the mass, for the neutrons to escape. As soon as one more neutron is released than escapes from the mass, the mass becomes critical, and the chain reaction accelerates tremendously.

As the number of fissions multiplies, sustaining the chain reaction, energy is released from the nuclei as heat. While the mass remains critical, energy is being constantly released, and the mass reaches the melting point. When the mass melts, the surface area increases and enough neutrons can now escape so that a chain reaction cannot be sustained (step 7). Only an instant is required for the mass to become critical and melt.

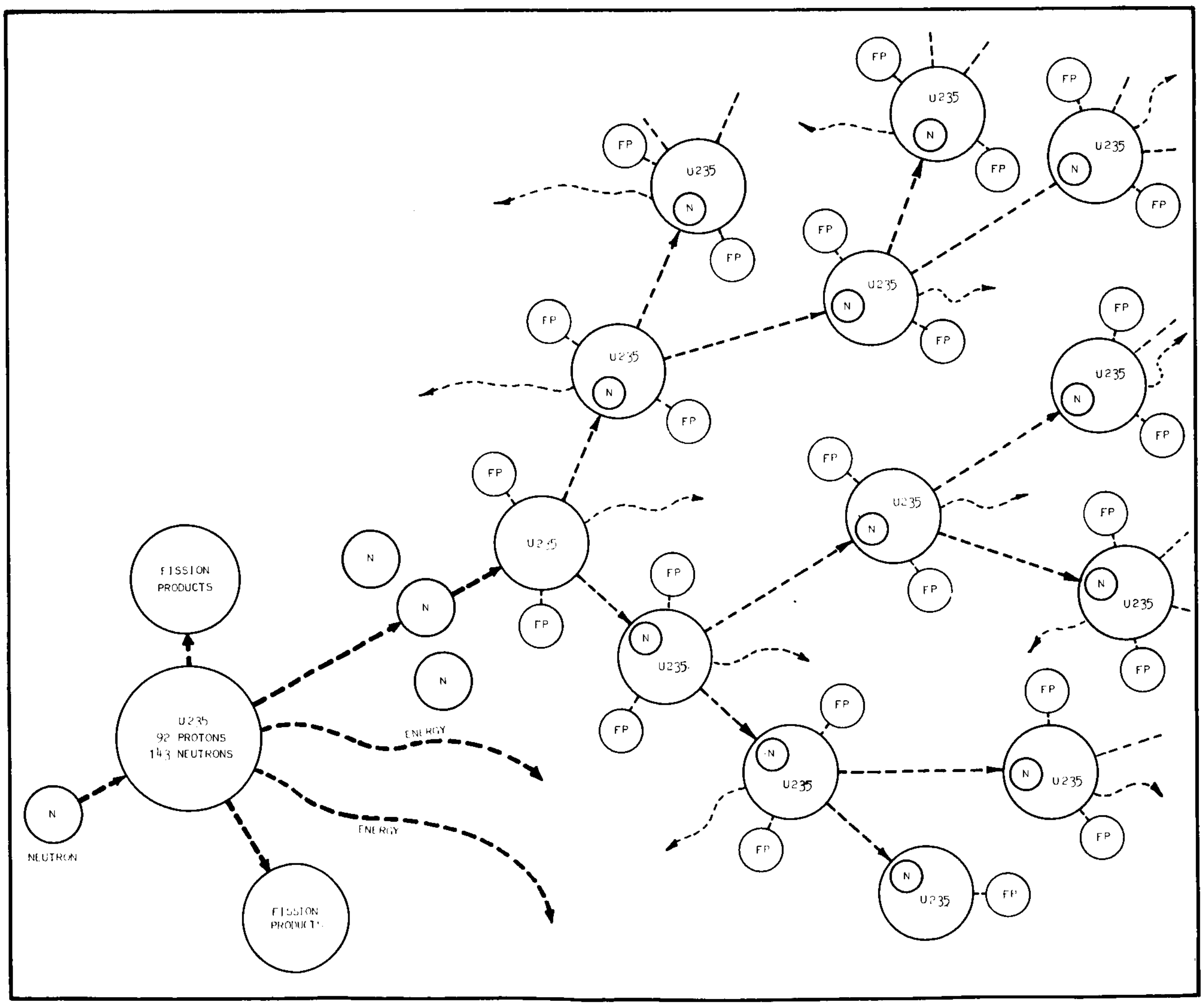


Figure 1-3. Chain Reaction

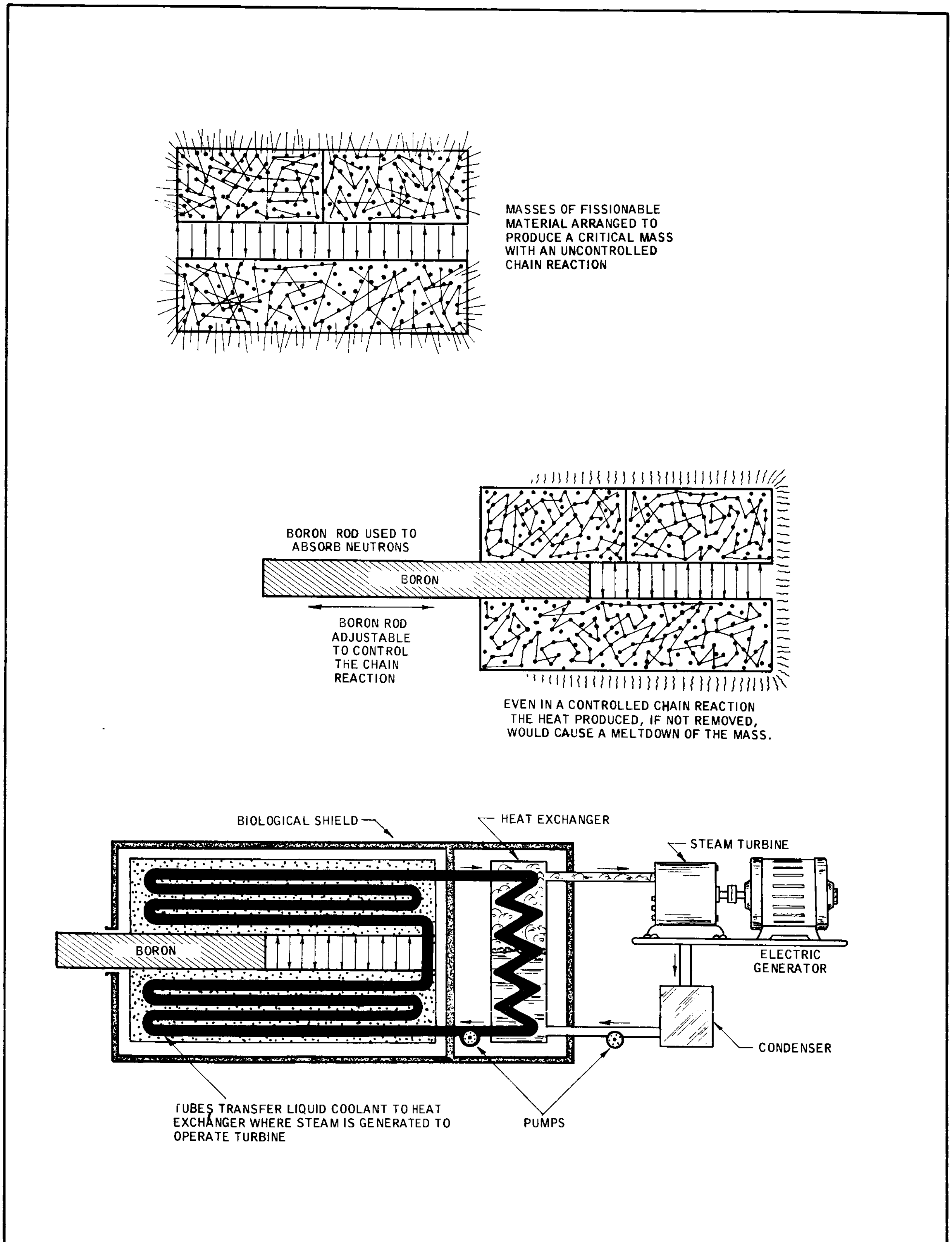


Figure 1-4. Critical Mass Buildup

During the critical mass stage there was a burst of gamma radiation, extremely hazardous to personnel. There was also a burst of neutron radiation, hazardous to personnel immediately present, and a certain amount of heat. Fission products, releasing various radiations with a variety of half-lives, were produced from the mass. Because of the heat generated, the fission products could be widely distributed by convection currents in the air, contaminating the area with radioactive material.

Personnel close to the mass when it became critical could have been seriously injured or killed. Personnel entering the area afterwards would require protection against radiation from the fission products. Protection against gamma radiation is achieved by restricting time in the area to a minimum, and against beta radiation by wearing suitable clothing.

Note that when the mass became critical there would have been no nuclear detonation (atomic-bomb type explosion) because the mass was not confined. This is true of all explosives. When an explosive is confined and initiated conventionally, there is an explosion. However, if the explosive material is unconfined and openly ignited, energy is released as usual, but without the explosive force. The energy liberated in both cases is wasted. However, the explosive can be employed to release energy in a useful manner; so can the critical mass, but less easily.

1-18. REACTORS

Figure 1-5 shows an arrangement of indivudual subcritical masses similar to that in figure 1-4. However, in figure 1-5, a boron rod is placed between the two subcritical masses. Boron absorbs neutrons as easily as a sponge soaks up water. Because of this, the rod absorbs the neutrons escaping from the subcritical masses which would ordinarily interact and increase the rate of fission. If the boron rod is pulled slowly out of the uranium, a point will be reached where a chain reaction is just started and sustained. The uranium will heat. If this heat is then dissipated into a heat-exchanger medium such as water, gas, or liquid metal, the uranium will not melt. The heat of the medium can be exchanged to water to generate steam, thus cooling the heat-exchanger medium and generating steam for power. An installation operating in this manner is called a nuclear power reactor.

This is the basic method of using nuclear energy to generate power. Such reactors vary; some use natural uranium rather than enriched uranium. Reactors also vary in the arrangement of fissionable material. In some reactors the fuel is in the form of solid rods; in others the fuel is slurried in a liquid. The type of cooling medium also varies in reactors.

If the reactor begins to malfunction, the boron is quickly moved into the fuel section and the reactor stops. This emergency shutdown of a reactor is known as the <u>scram</u>. Boron and similar materials which stop the chain reaction are known as <u>reactor poisons</u>.

Another use of the reactor is producing artificial radioisotopes. For a material to become radioactive, it must be subjected to neutron bombardment. Reactors furnish a controllable method of doing this. Figure 1-6 illustrates a typical example.

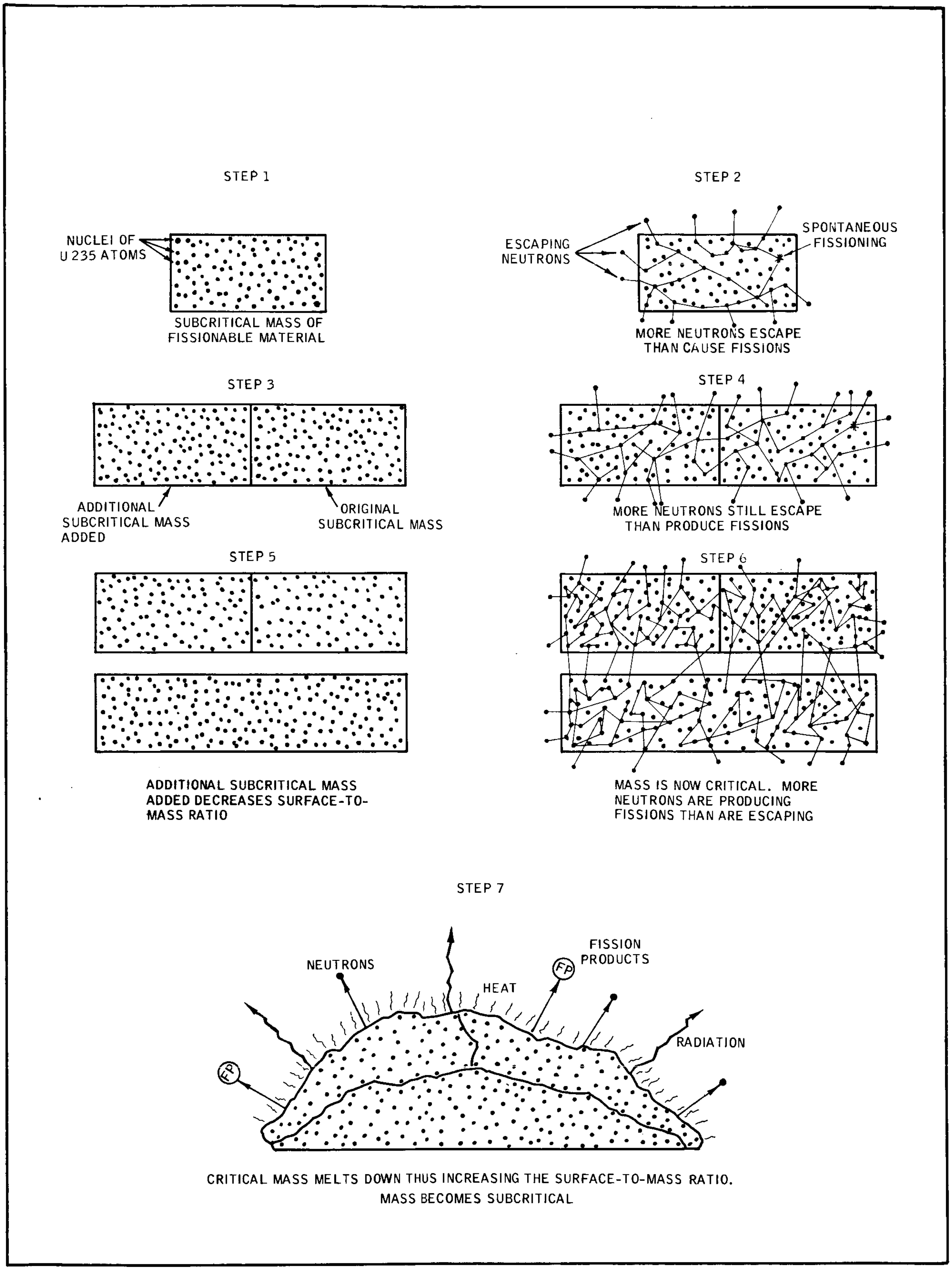


Figure 1-5. Nuclear Reactor Concept

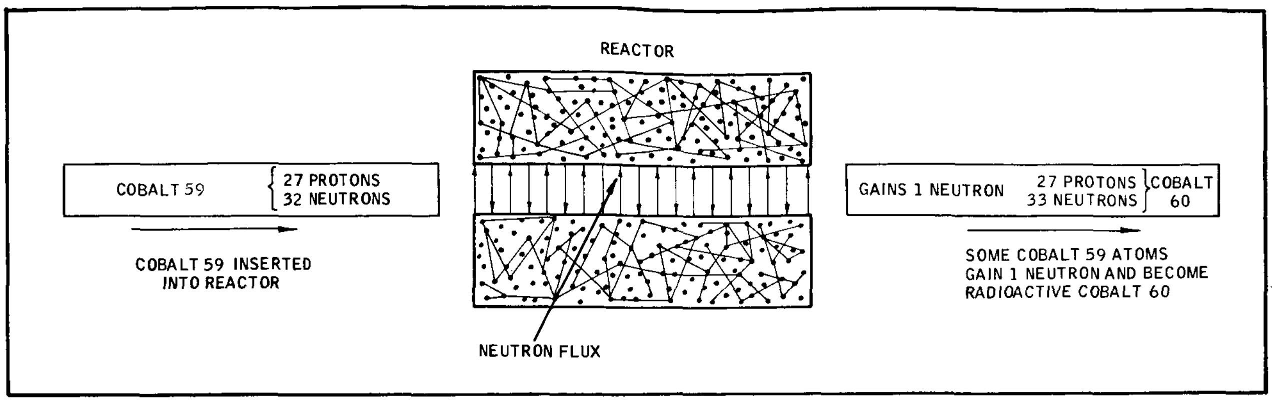


Figure 1-6. Reactor Preparation of Radioactive Isotope

Some cobalt metal is inserted into a hole in the reactor. Natural cobalt has 27 protons and 32 neutrons. There are no natural isotopes. When the cobalt is placed in the reactor, its atoms of cobalt 59 are subjected to an intense bombardment of neutrons (neutron flux). Possibly one cobalt 59 atom in a billion captures a neutron and now has 33 neutrons instead of 32. These atoms are now cobalt 60, a radioisotope of cobalt. Cobalt 60 emits gamma radiation and some beta particles, and has a half-life of 5.4 years

When the cobalt is removed from the reactor, it is still cobalt chemically. However, possibly one-billionth is radioactive cobalt 60. The cobalt 60 is not separated from the cobalt 59; this would involve a very difficult process. Cobalt 60 is widely used in radiography, therapy, and many other applications.

1-19. REFLECTORS AND MODERATORS

Step 4 of figure 1-4 shows a subcritical mass; that is, an amount of fissionable material insufficient to sustain a chain reaction. If this mass were surrounded with a material that would cause neutrons to bounce back into the fissionable material, very few neutrons would escape. In effect, the neutrons would have more than one opportunity to strike a nucleus and effect a fission of that atom. Such a material is called a reflector. It is designed into the construction of a reactor to conserve neutrons.

Many common substances, such as those rich in hydrogen or other light elements, have this ability. Consequently, accidentally placing a neutron-reflecting material close to a subcritical mass could create a critical-mass situation.

For a neutron to enter an atom and cause fission, the neutron must be traveling at exactly the right speed. Materials which slow down the neutrons are called moderators. Accidental mixing of fissionable material with a moderator might produce a critical-mass condition. For example, water is both a moderator and reflector. A container of fissionable material chips might be a subcritical mass. Filling the container with water, however, might add enough reflection and moderation to change the situation to a critical-mass condition.

From the above discussion, it is evident that handling fissionable material demands strict adherence to regulations on spacing, shape, moderation, reflection, etc.

1-20. X-RAYS

X-rays are electromagnetic waves produced in a vacuum tube when high-voltage electrons strike a metal target. The negative electrons are slowed down by the attraction of the positive nuclei in the target atoms. The slowing-down of these electrons results in a loss of energy, which is given up as electromagnetic radiations, or X-rays. X-rays have extremely short wavelengths. The terms soft and hard are used to designate the penetrating power of the X-ray beam. The harder the radiation, the shorter the wavelength and the greater the penetrating power. The frequencies of X-rays and gamma rays overlap on the electromagnetic spectrum (figure 1-7). Gamma rays and X-rays of the same frequency would, therefore, have very nearly identical properties, and protecting personnel from them would present similar problems.

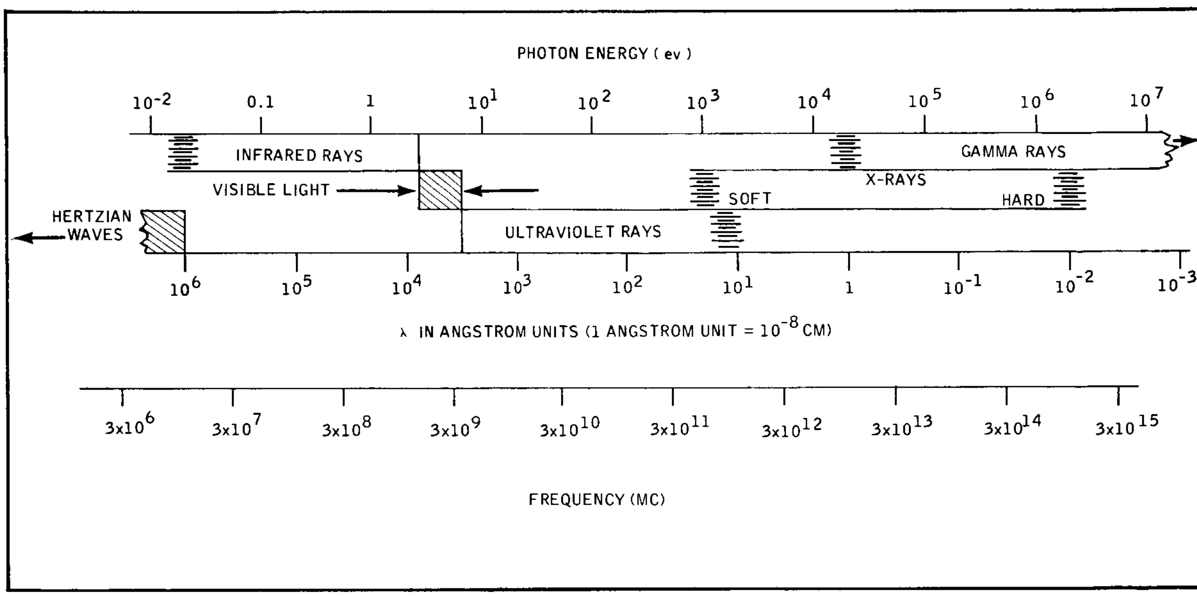


Figure 1-7. Electromagnetic Spectrum

These problems, however must be met in different ways because of the differences in the equipment involved. Material radiating gamma rays may be placed in an approved receptacle to prevent irradiation of attendant personnel. The X-ray tube, on the other hand, presents a different problem. Because it is much larger, and because of its electrical conductors, shielding the X-ray equipment is more difficult. A radiation source of this size scatters radiation in the vicinity. Therefore, not only the X-ray beam, but also the scattered radiations, must be considered as hazards.

X-ray tubes produce X-rays for a definite and useful purpose. However, they are not the only source of X-rays. X-rays are also produced by high-energy electrons striking a metal target in many modern high voltage electron tubes. Klystrons, thyratrons, magnetrons, and other tubes of high-power electronic equipment generate dangerous amounts of X-rays. Therefore, they must be shielded to protect personnel in the vicinity.

1-21. CURIES

The amount of radioactive material present is expressed in curies. A curie is that amount of radioactive material which is decaying at the rate of 37 billion atoms per second. Therefore the curie bears no direct relationship to the weight of the material involved. If a material is only slightly radioactive, several thousand pounds might be required for one curie of radioactivity. On the other hand, if the material is highly radioactive, a fraction of an ounce might be a curie. The curie, then, is not a measure of radiation hazard from the material. The hazard exists in the quantity and type of radiation emitted, not in the rate of atomic decay. Refer to table 1-2 for the half-life and curie measure of some commonly used radioisotopes.

1-22. COMMON TERMS

Appendix A of this handbook provides a convenient glossary of terms commonly used in reference to the chemical and physical properties of matter or energy and its behavior. Some of the terms have been purposely shortened to eliminate unnecessary detailed techniques, description of equipment, or complex mathematical theory.

Table 1-2. Half-Life and Curie Measurements of Common Radioisotopes

Isotope	Half-Life	Quantity Required to Equal	
		500 Millicuries	10 Millicuries
Argon 41	109 minutes	0.01 microgram	0.0002 microgram
Potassium 42	12.4 hours	0.08 microgram	0.0016 microgram
Sodium 24	15.1 hours	0.06 microgram	0.0012 microgram
Gold 198	2.7 days	2.05 micrograms	0.041 microgram
Iodine 131	8.1 days	4.1 micrograms	0.082 microgram
Phosphorus 32	14.3 days	1.75 micrograms	0.035 microgram
Chromium 51	27.8 days	0.55 microgram	0.011 microgram
Iron 59	45 days	10.2 micrograms	0.204 microgram
Strontium 89	53 days	18 micrograms	0.36 microgram
Iridium 192	74 days	5.5 micrograms	0.11 microgram
Sulfur 35	87 days	11.5 micrograms	0.23 microgram
Polonium 210	138 days	111.5 micrograms	2.23 micrograms
Calcium 45	163 days	27 micrograms	0.54 microgram

Table 1-2. Half-Life and Curie Measurements of Common Radioisotopes (Cont.)

Isotope	Half-Life	Quantity Required to Equal 500 Millicuries	Quantity Required to Equal 10 Millicuries
Zinc 65	250 days	65 micrograms	1.30 micrograms
Iron 55	2.9 years	222 micrograms	4.43 micrograms
Cobalt 60	5.3 years	440 micrograms	8.8 micrograms
Krypton 85	10.3 years	5.2 milligrams	25 micrograms
Hydrogen 3	12.5 years	0.05 milligram	1 microgram
Strontium 90	25 years	3.15 milligrams	63 micrograms
Cesium 137	30 years	5.75 micrograms	0.115 microgram
Radium 226	1620 years	0.5 gram	10 milligrams
Carbon 14	5800 years	0.12 gram	2.3 milligrams
Plutonium 239	24,000 years	8 grams	160 milligrams
Uranium 235	7.1×10^8 years	525 pounds	10.5 pounds
Uranium 238	4.5×10^9 years	3300 pounds	66 pounds
Thorium 232	1.4×10^{10} years	5 tons	200 pounds

SECTION II

KSC ORGANIZATION FOR RADIOLOGICAL SAFETY

2-1. ORGANIZATIONAL CHART

The organizational chart for KSC radiological safety is shown below. The detailed functions and responsibilities of each group is explained in the following paragraphs.

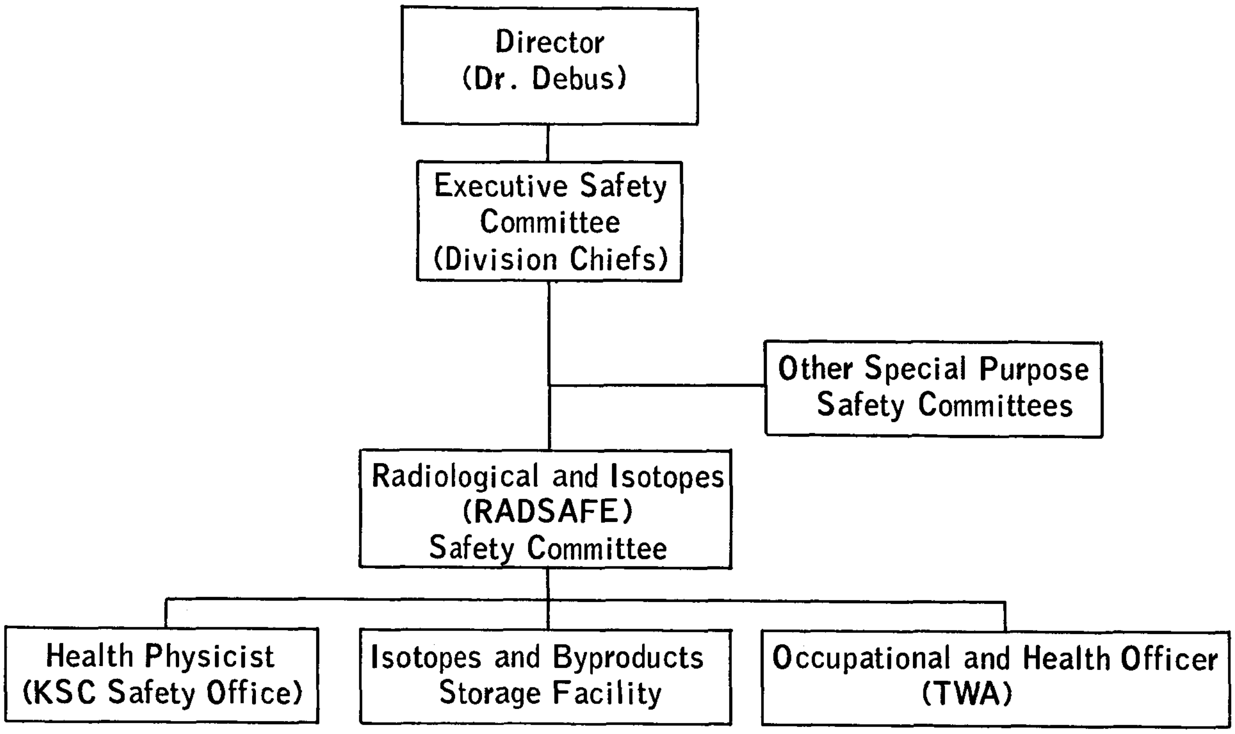


Figure 2-1. NASA RADSAFE Program Organizational Chart

2-2. EXECUTIVE SAFETY COMMITTEE

2-3. Purpose. The KSC executive safety committee is responsible to the director of KSC for the overall safety program, including the RADSAFE program and other special purpose safety committees. The membership of the executive safety committee is composed of the directors and chiefs of the various NASA activities at KSC and key managers within the activities.

2-4. Responsibilities. The executive safety committee is responsible for the following:

a. Provide for top management review, guidance, and support of the overall NASA-ETR-MILA safety program.

b. Provide a review of proposed changes to NASA safety policies and procedures which are of major consequence or affect more than one NASA activity.

Such modifications may be required by changes in mission, technology, or as a result of special tests or studies.

2-5. RADIOLOGICAL AND ISOTOPES SAFETY COMMITTEE

2-6. Membership. The radiological and isotopes (RADSAFE) safety committee is one of the special purpose safety committees appointed by the KSC director. Its membership shall include the health physicist and representatives from the following organizations:

a. Office of Assistant Director for Plans and Projects Management (P).
b. Facilities Engineering and Construction Division (F).
c. Goddard Space Flight Center - ETR.
d. Field Projects Branch (GLO).
e. Manned Spacecraft Center - Florida Operations.
f. Electronic Engineering and Instrumentation Systems Division (V).
g. Base Operations Division (G).

2-7. Responsibilities. The RADSAFE committee is established for the general purpose of assuring adequate facilities, equipment, training, and operational control to properly protect persons and property from the hazards of radiation sources. It will advise and assist the health physicist in the discharge of management duties delegated to him, will constitute the KSC isotopes committee as identified in Title 10, Part 30, Code of Federal Regulations, and develop requirements for radiation safety. The committee's specific functions shall include the following:

a. Review and approve all proposals for utilization of potentially hazardous radiation sources.
b. Formulate radiation safety policies and control and regulate the acquisition of radiation sources. All proposals for use of ionizing radiation sources shall be reviewed and approved by the committee prior to purchase of the proposed radioisotopes, materials, and equipment.
c. Review and approve procurement specifications and exercise control over distribution, use, accountability, and disposal of radioisotopes and radioactive materials and devices.
d. Establish requirements for storage and utilization facilities for radiation sources, and evaluate such facilities prior to initial use and major changes in use.
e. Establish radiological health measures.
f. Establish and assign operating safety functions and responsibilities.
g. Review and approve operating and emergency procedures for radiation sources.
i. Review and approve proposals to transfer custody or location of radiation sources.

2-8. SAFETY OFFICE HEALTH PHYSICIST

The Safety Office will assist the RADSAFE Committee as directed. Particularly, the office will provide the following support:

a. Maintain a current record of all sources of ionizing radiation at KSC, to include:

1. Type of source and custodian.
2. Activity of source or voltage of device.
3. Type of emanation.
4. Location of source storage.
5. Location of source or device usage.

b. Maintain complete dosimetry records on all individuals employed by or under contract to KSC who are exposed to ionizing radiation, as required by Title 10, Part 20, Code of Federal Regulations.

c. Maintain a supply of film badges; issue them to custodians, and assure that they are processed monthly.

d. Maintain a supply of copies of this handbook and copies of other pertinent documents and regulations on radiological safety for issuance to such personnel as the health physicist may direct.

e. Maintain a supply of pertinent forms for issuance as needed.

f. Maintain complete records of all cases of procurement, shipment, transfer, or disposal of radiation sources at KSC.

g. Maintain complete records of all KSC monitoring instruments.

h. Publish memoranda and circulars, and revise the radiological safety handbook as required.

i. Prepare a budget for the RADSAFE program on a fiscal-year basis, and submit it to the RADSAFE committee for approval at such date as may be prescribed.

j. Prepare and submit to the RADSAFE committee for approval, revisions to, or applications for licenses to possess radiation sources.

k. Determine the training needs of KSC personnel; arrange with Training Branch, Organization and Personnel Division for necessary training programs and courses in radiological safety, and review and approve the content of such courses.

No radiation source or monitoring device will be in the possession of KSC personnel or on premises under KSC jurisdiction without the approval of the Safety Office.

2-9. TWA OCCUPATIONAL HEALTH OFFICER

The occupational health officer is responsible to the radiological and isotopes committee. He has the authority as well as the responsibilities to conduct investigations and to advise the RADSAFE committee on all phases of the RADSAFE program. To safeguard life, health, property, and the public, his recommendations shall take precedence over all work requirements. Specifically, his responsibilities will be the following:

a. Assume responsibility for all radiation sources with the exception of KSC payload devices.

b. Advise custodians in establishing and maintaining operational procedures to keep radiation exposure to a minimum.

c. Investigate any abnormal radiation exposure to determine its cause, and have corrective measures established to eliminate its recurrence.

d. Assure that personnel monitoring devices are worn in radiation areas as defined in Title 10, Part 20, Code of Federal Regulations.

e. Conduct routine radiation surveys as outlined in Title 10, Part 20, Code of Federal Regulations and/or Section IV of this handbook, or as prescribed by the RADSAFE committee.

f. Assure that the periodic leak tests of sealed sources as required in Title 10, Part 30, Code of Federal Regulations are conducted.

g. Review requests for procurement of, and proposed operations with, radioactive material and sources of ionizing radiation; recommend approval or disapproval to the RADSAFE committee.

h. Furnish the Safety Office with a current list of all material possessed by KSC.

i. Ensure compliance with AEC or other federal requirements not covered by the above responsibilities.

2-10. ISOTOPES AND BYPRODUCTS STORAGE FACILITY

The RADSAFE committee is responsible for the safe storage and disposal of radioactive materials. Section IV of this handbook contains specific information relative to the storage and/or disposal of radioisotopes and radioactive byproducts.

2-11. SPECIAL PURPOSE SAFETY COMMITTEES

In addition to the RADSAFE committee, there are four other special purpose safety committees. Specifically, they are:

a. Electrical Safety Committee.
b. Explosives Safety Committee.
c. High Pressure and Cryogenics Safety Committee.
d. Industrial Safety Committee.

Their responsibilities are to assist each supervisor in the consideration of safety problems and the development or modification of safety controls relative to the special skills and cognizant areas of the selected committee members.

2-12. TRAINING PROGRAM

A training program will be prepared and sponsored by the Safety Office and approved by the RADSAFE Committee. The KSC training section will conduct the program. The training program will consist of two courses: a long one and a short one.

2-13. USERS OF RADIATION SOURCES

Personnel whose duties involve the actual use or handling of radioactive sources, supervisory, or safety functions in this field, or presence in areas where radioactive hazards exist shall attend the long training course.

2-14. SECURITY AND FIREFIGHTING PERSONNEL

Personnel whose duties might necessitate an emergency entrance to areas where radioactive sources are present shall attend the long training course. Such personnel shall be familiar with the locations of radioactive sources at KSC, the nature of the hazards involved, precautions necessary in approaching such areas, and measures to reduce spread of contamination or other hazards which might result from fire or other disaster.

2-15. OTHER RESPONSIBLE PARTIES

Personnel whose normal duties might cause them to come into or near a radiation area shall be given the short training course.

SECTION III

BIOLOGICAL EFFECTS OF RADIATION

3-1. GENERAL

Radioisotopes, X-ray producers, and nuclear reactors are not the only sources of radiation. There is, in addition, a natural background of radiation which is always present. Everyone is exposed, to some degree, to this radiation, whether or not they are actively engaged in using radioisotopes and X-rays. Consequently, we all absorb a certain amount of radiation during our lifetime.

3-2. INHERENT HAZARDS

Radioactive materials emit energy which can damage living tissue. Unquestionably this is a serious hazard and, if not controlled, can cause injury or death. However, the hazardous effects can be controlled, and great benefit can be derived from the energy of radiation, so it is reasonable to use radioactive materials constructively.

Exaggerated accounts of radiation dangers have led some to choose not to be exposed at all. However, it is not possible to avoid some exposure to radiation. Natural sources of radiation preclude the possibility of totally avoiding exposure. For instance, everyone is exposed to cosmic radiation from outer space. The intensity of cosmic radiation increases with altitude. Consequently, a person living a mile above sea level would receive twice the amount of radiation that one would receive at sea level. Deep in a mine and free from cosmic rays, one working there would be exposed to radiation from the radioactive materials in the earth's crust. Added to this natural background of radiation are the radioactive elements in the human body, such as carbon, potassium, and sodium.

Added to all these is the radiation received from diagnostic and therapeutic treatments. Since any radiation can damage tissue, so can medical and dental X-rays. However, the benefits realized from X-rays and radioactive materials outweigh the risks when they are used under careful control to combat disease and injury.

So, from the radiation in the earth, space, the radioactive materials in the human body, and from medical exposures, it is impossible to totally escape some radiation.

3-3. RADIATION SICKNESS

Radiation sickness generally results from either improper radiation therapy or exposure to a nuclear blast. The former kind usually follows large doses of radiation, particularly to the abdominal region. The symptoms of this type of sickness are nausea, diarrhea, vomiting, and psychic depression. These effects usually begin a few hours after treatment, and in some cases may subside within one day. The severity and duration depend upon the dose and the individual. Radiation sickness resulting from an acute exposure to a nuclear blast is potentially more serious. The effects will vary with the amount of radiation absorbed. Shortly after exposure, the victim will experience nausea and vomiting. The symptoms may last for a few hours and then disappear for a while. After a variable period of inactivity, there will be a recurrence of nausea and vomiting accompanied by internal disorders, loss of hair, and blood infections. The severity of these illnesses varies. They may result in death, partial recovery, or apparent complete recovery. As a rule, the seriousness of the final results can be judged by the severity of the initial illnesses and how quickly they occur.

3-4. RADIATION INJURY

A radiation injury is the localized effects of an overdose of radiation to a particular part of the body, usually the hands. They are more often in contact with or nearer the source than the rest of the body. A radiation injury may manifest itself in the form of burns, loss of hair, skin lesions, sterility, or genetic damage. However, many injuries are temporary and the body's normal healing processes take care of these. Others may be so slight that the victim would not be aware of them without clinical observation.

3-5. RADIOACTIVE POISONING

Radioactive poisoning results when a dangerous amount of radioactive material enters the body by any method. It can cause such diseases as anemia and cancer. The organs affected and the length of time the radioactive material remains in the body depend upon the type of material (radium, cobalt, etc.). Precautions must be taken to prevent particles of radioactive material from entering the body.

3-6. CONTAMINATION

Contamination results from the undesirable distribution of radioactive material in an area, on personnel, or on tools and equipment which otherwise should be free of radioactive materials. Whenever radioactive materials which could be spread accidentally are handled, all personnel will understand the contamination possibility and will know the decontamination procedures. The seriousness of contamination depends upon the material, amount and type of radiation emitted, intended use of contaminated area, and the degree of personnel involvement. For example, a laboratory making precise radiation measurements will find any amount, however small, of undesired radioactivity a problem. Such contamination would greatly hinder the work by raising the background level of radiation. On the other hand, a building or a piece of equipment may be so severely contaminated that abandoning or disposing of it in a prescribed manner would be more economical than decontamination. Decontamination procedures are given in Section IV.

3-7. BIOLOGICAL UNITS

. The strength, duration, and biological effects of radiation are carefully measured and calculated in order to minimize the amount of radiation a person is exposed to during his lifetime. Specific terms have been assigned to these units. These terms and related quantities will be referred to throughout this handbook.

3-8. Roentgen. The term roentgen (r) is used to express the quantity of X or gamma radiation that will produce a given amount of ionization in a specific quantity of air. (See appendix A). The number of roentgens, or milliroentgens, to which the total body or any portion of the body is exposed to external radiation is the radiation exposure dose and will be expressed in roentgens.

3-9. RAD. The RAD is the unit of measure of the absorbed dose of any type of radiation. However, a RAD of one type of radiation may have more or less biological effect on the body than one RAD of another type. The difference of effect is expressed by the relative biological effectiveness (RBE).

3-10. Relative Biological Effectiveness. The relative biological effectiveness expresses the difference of effects one rad of a particular type radiation may have on the body as compared to another type. For instance, the RBE of gamma radiation is one. The RBE of some types of alpha radiation is 20. This means that one RAD of an alpha radiation will have 20 times the effect in the body as one RAD of gamma radiation.

3-11. Roentgen Equivalent Man. The roentgen equivalent man (rem) is the unit of measure which expresses all types of radiation exposures in man. Table 3-1 shows the relationship between the radiation dose in RADS, RBE, and the exposure in rems.

Table 3-1. Relative Biological Effectiveness of Different Types of Radiation.

TYPE OF RADIATION	DOSE IN RADS		RBE		DOSE IN REMS
Gamma	1	X	1	=	1
Beta	1	X	1	=	1
Alpha	1	X	20	=	20
Neutron	1	X	10	=	10

3-12. EXTERNAL RADIATION

Radiation presents a health hazard to the body in two entirely different ways. One, by radiation originating from a source outside the body, and the other from within the body. Of the two, exposure to external radiation is probably the one most frequently encountered. However, for complete protection against an overdose of radiation, both types must be controlled and monitored. Since both types of radiation present two separate problems, each will be covered separately.

3-13. GENERAL

External radiation exists in two forms: one, long-range (hard), highly penetrating external radiation, and two, short-range (soft), less penetrating external radiation. The hard radiations include X and gamma rays; however, X-rays are often classified as hard or soft as to their frequency. The short-range or soft radiation are beta and fast neutron radiations. Because the beta rays have a shorter range and are less penetrating, they do not present the external hazard associated with X and gamma rays. The beta rays represent an external hazard only when a person comes in close contact with the source. Also, the source may be handled and some of the material deposited on the person's body and not removed. Therefore, unless otherwise indicated, the following material will contain information relative to X and gamma radiation.

External radiation strikes the body much the same way as a beam of light. For the sake of simplicity, visualize the beam of radiation as being composed of many individual, closely-grouped rays. Each ray in this case is a separate bundle of energy. Each ray will do one of two things to the body. One, it will penetrate to some depth and expend its energy, or, two, it will pass completely through the body without imparting any energy (figure 3-1). This is a grossly simplified explanation of the complex subject of radiation effects; however from a factual viewpoint, it will serve the purpose for this discussion.

In figure 3-1, the hard radiations emitted from a radioactive material are directed toward the total body area. Each ray penetrates the body. Some of them penetrate to varying depths before they strike a target and have an effect upon the body. Other rays completely penetrate the body and thus have no effect. Consequently, it is the amount of radiation that gives up its energy within the body that causes organic damage.

Some of the radiation passes through the body because it, as all matter, is mostly space. The rays directed toward the body travel in a straight line and may penetrate quite a distance before they strike an atom.

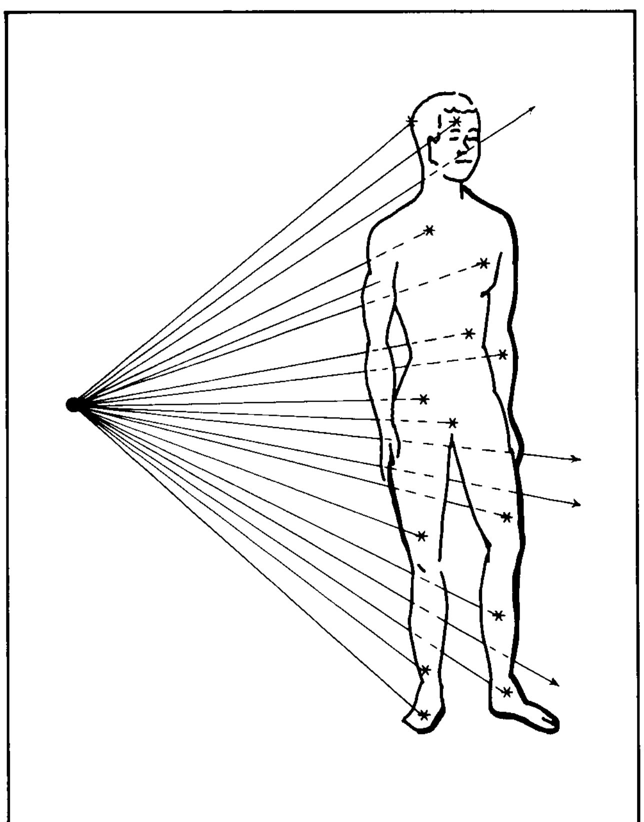


Figure 3-1. Radiation of Body by Radioactive Source

The rays from radioactive material do not strike atomic nuclei in significant quantities. Few of the rays have sufficient energy to penetrate the atom to the depth of the nucleus. They do, however, strike the electrons and thus give up their energy. The damage done by the rays results from the electrons being knocked out of the atoms. If enough atoms lose electrons due to this energy exchange, radiation damage results. The number of atoms in an organ or area of the body is inconceivable. Thus, the damage of a few atoms would be inconsequential.

The body is constantly undergoing these radiation effects as a result of radiation received from natural sources, water, food, and in some cases occupational environments. When an electron is knocked off an atom, the cell of which the atom is a member is damaged. The body has the ability to repair such damages, although the rate and extent of the repair varies with the individual. In low level radiation, this repair mechanism compensates for the body damage. On the other hand, excessive radiation can cause damage beyond the body's repair capability; then organic damage or possibly death may result. The desired situation is to establish a level of exposure that can be tolerated by the body without any harmful effects during one's lifetime.

3-14. SINGLE EXPOSURES

The ability of each individual to withstand different amounts of radiation and still live, precludes the possibility of specifically stating the amount of radiation required to kill any one individual. However, it is quite certain that no human being could survive 1000 roentgens of total body radiation delivered in a short space of time (figure 3-2).

Both of these conditions are important. The effect of 1000 roentgens of radiation delivered to the whole body is by no means the same as 1000 roentgens delivered to the hand or other small area of the body. Similarly, a third degree burn of a large area of the body is not the same as a third degree burn of the hand. In both cases, however, damage will be done, death in one case and local injury in the other.

The short space of time is also important. It is defined as 24 hours or less. The ability of the body to withstand and recover from an injury increases as the same amount of injury is spread over a larger period of time.

The radiation dose required to kill one specific individual is not an accurate measure of the fatal dose to others because of individual differences. The term that is used is the median lethal dose, or LD/50. This is the dose required to kill 50 percent of those subjected to it. The LD/50 for external penetrating radiation is 500 roentgens delivered to the total body in a short space of time. That is, if a random sampling of the population were subjected to 500 roentgens of hard radiation within a 24 hour period, 50 percent of them would recover. However, those who recovered would have experienced the effects of radiation sickness. The progressive dose rate is shown in figure 3-2.

At 200 to 250 roentgens of total body exposure in a short space of time, the first death would be expected.

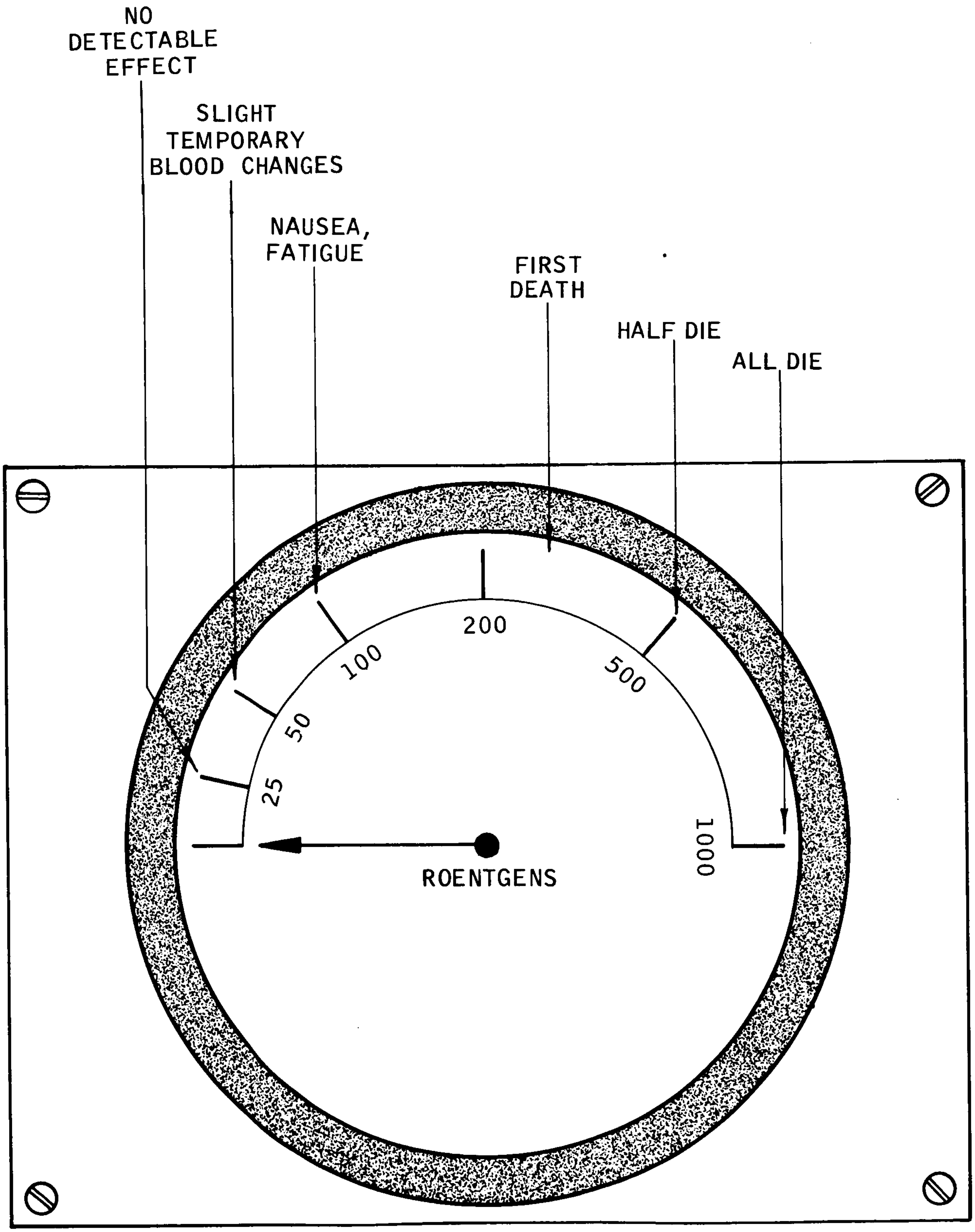


Figure 3-2. Effects of External Radiation

From 100 to 200 roentgens of total body exposure in a short time, the victims would experience nausea, fatigue, vomiting, and blood changes, but no deaths would be expected.

At about 50 roentgens of total body radiation in a short time, the victim would experience temporary blood changes which the body would correct in time. These changes would be detectable only by clinical tests.

At 25 roentgens of total body exposure in a short time, there would probably be no detectable effects.

3-15. CONTINUOUS EXPOSURE

The effects of a single incident of radiation exposure, one in which the victim would die, become ill and recover, or suffer no ill effects, were previously discussed. This type of radiation incident can be equated to an ordinary injury accident, one in which a ladder collapses causing a worker to fall. The worker may die, suffer injuries from which he might recover, or suffer no injuries at all. Whatever the case, the accident is done and over with, and the effects are ended.

In addition to single exposures, there is another possibility with radiation--the problem of repeated small exposures over an extended period of time. It is the accumulative total of radiation during one's lifetime, and the effects of it, that are to be considered when establishing the total permissible dose in rems.

There are two points to consider when establishing this level. First, how is the individual affected by radiation. That is, what damage will be done to the individual by repeated small doses of radiation over a period that could extend from the time he enters industrial employment until he retires.

The second point to consider would be the genetic effects with respect to society. This is the problem of genetic damage which could result in defects in future generations by the exposure of large numbers of individuals to radiation.

3-16. Individual Effects. In regards to the direct effect on the individual, high doses of radiation received over a relatively short period of time can have some effect on the life span. There is no conclusive evidence, however, that low doses spread over a period of years have any life-shortening effects. Nor is there a level of radiation exposure below which it can be said there is no life-shortening effect at all.

In addition to the penetrating qualities of the radiation, there are several other factors to consider. For example, when the entire body is exposed to radiation, all organs are irradiated; however, some receive larger doses than others. The difference in dose from organ to organ depends, generally, on the penetrating power of the rays and factors such as the distance of the body from the source, the duration and intensity of the radiation, and the depth of the organ. Consequently, the local and overall effects produced are largely dependent on the tissue dose distribution throughout the body. (The tissue dose is expressed in RADS and may vary enormously).

Thus it is generally assumed that the effect produced in any given tissue or organ is due greatly to the tissue dose delivered to it. When the entire body is irradiated more or less uniformally, innumerable changes can occur. But it is possible that an organ may not experience any radiation damage. However, the organ may be damaged due to the functional failure of another organ, or to blood changes manifested in the organ by the circulatory system. For practical purposes, it must be assumed that the dose received by a certain organ is largely responsible for the biological damage resulting in it. In addition, the resulting damage will also depend upon the susceptibility of the organ to radiation.

3-17. Genetic Effects. In addition to the organic damage which an individual may incur due to radiation, this same radiation may also produce changes in the genes and chromosomes in the body cells. The subsequent genetic damage may affect future generations when they occur in the germ cells. Experiments have shown that genetic changes can be produced with low doses of radiation. The occurrence of genetic damage in gene mutations is directly proportional to the dose and is independent of the duration of the exposure. In chromosome breaks in which the fragments later form abnormal unions, the frequency of this occurrence depends on the dose rate within certain limits. Regardless of the susceptibility of the individual, some injury of this type is unavoidable. Some cells in his body, including some germ cells, will be genetically altered. However, it is important to note that genetic changes of the same kind occur simultaneously. Thus, genetic changes occur in the absence of exposure to excess radiation. The primary objective is to control exposure in such a way that the eventual effects of genetic injury are not too large in comparison with the occurrence of spontaneous genetic abnormalities. In concern for the welfare of future generations, gene mutations with inconspicuous manifestations play the most important part. The controlling factor is the number of undesirable genes present in the general population in which the intermarriage occurs. The majority of these genes would probably have no recognizable effects for several generations, but within future generations they could result in undesirable conditions.

The portion of the population that is of interest genetically is that portion in which a substantial birth rate is probable. The effect of radiation damage on genetic matter is different than the effect on other cells. When the genetic material is damaged, a pattern, i.e., inherent characteristics, is damaged. Once a pattern is damaged, it remains damaged. It should be noted, however, that all radiation damage will not have genetic effects. Only that radiation which strikes the reproductive organs is of genetic significance. Radiation exposure of other organs and areas of the body has no genetic effect whatsoever.

3-18. SUSCEPTIBILITY

The susceptibility of various organs and tissues to radiation varies, as well as the ability of the organs and tissues to recover. Likewise, the location of the tissues and organs within the body and in respect to the radiation source will affect the distribution of radiation in the body. For instance the skin, or the tissue layers immediately beneath, receive the highest dose in roentgens, and certain deep-seated tissues the lowest. The skin can withstand large doses of radiation, and due to its location incurs more than other tissues. However, this does not preclude the possibility that a more susceptible tissue or organ may receive a damaging dose of radiation while the skin suffers no appreciable ill effects. Therefore, it is the most susceptible organs and tissues that must be considered in relation to radiation exposure levels.

3-19. Skin. Human skin is quite radiosensitive, but recovery is rapid. Therefore, when exposure extends over a long period of time, a much larger total dose is required to produce a given effect. Because cancer of the skin is generally curable and leukemia is always fatal, the danger of overexposing the bloodforming organs is much more serious. Based on this, the tolerable dose for the bloodforming organs would necessarily be much smaller than for the skin. In actual practice, however, the aim is to prevent development of cancer in either case.

Skin damage occurs mostly in the lower layers where cells are damaged and have ceased to function. Therefore, it is this area that is of greater interest, rather than the surface cells as they are constantly being replaced by new ones.

3-20. Bloodforming Organs. The bloodforming organs constitute a portion of the critical tissues with respect to radiation damage in the body. The bloodforming organs are the liver, spleen, bone marrow, and lymph nodes. The susceptibility of these organs to radiation is greater than skin tissues. Generally, these organs are to be subjected to only half as much radiation as the skin. Exposure of the bloodforming organs to radiation over a period of years has been connected to the incidence of anemia and leukemia. Therefore, exposure to radiation should be kept below the level at which appreciable permanent damage may be produced in the bloodforming organs.

3-21. Gonads. Considering the genetic damage which may be manifested in future generations, the gonads, of course, constitute the most critical tissues. In addition, the gonads must be considered as critical tissues because of the danger of sterilization or impairment of fertility. The sensitivity to radiation of the gonads is considered to be the same magnitude as that of the bloodforming organs.

3-22. Lens of Eye. Radiological experience does not indicate any particular sensitivity of the eye lenses to radiation with respect to cataract formation. However, it is still considered a critical tissue due to its high sensitivity to fast neutrons. In the absence of evidence to the contrary, the radiosensitivity of the lens of the eye is considered to be the same as that of the other critical organs.

3-23. PROTECTION

The protective measures for external penetrating radiation are a combination of three things: time, distance, and shielding. That is, the amount of radiation that strikes the body is a factor of the length of exposure, the distance from the radiation source, and the type and thickness of the material between the body and the source. One of these protective factors alone cannot be used. The factor of time is always involved; but in combination with time, factors of distance or shielding or both, may be involved.

3-24. Time. The effect of time on radiation exposure is relatively simple. If an individual were in an area with a radiation level of 100 milliroentgens per hour (100 mr/h), then in one hour he would have received 100 millirems of exposure. If he stayed two hours, he would get 200; four hours - 400, and eight hours - 800 millirems. As shown in figure 3-3, the longer the individual stayed in the area the more radiation he would absorb.

Time is a major factor in determining the prescribed exposure levels for individuals. Consider, for example, a work area with a radiation level of 20 mr/h. The radiation exposure level for personnel has been fixed at 100 millirems per week. Based on five work days per week, each person could receive only 20 millirems per day. Thus, no one would remain in the area more than one hour each day, and it would be assumed his radiation exposure would not exceed the set limit. His actual radiation exposure level would be recorded by the use of film badges.

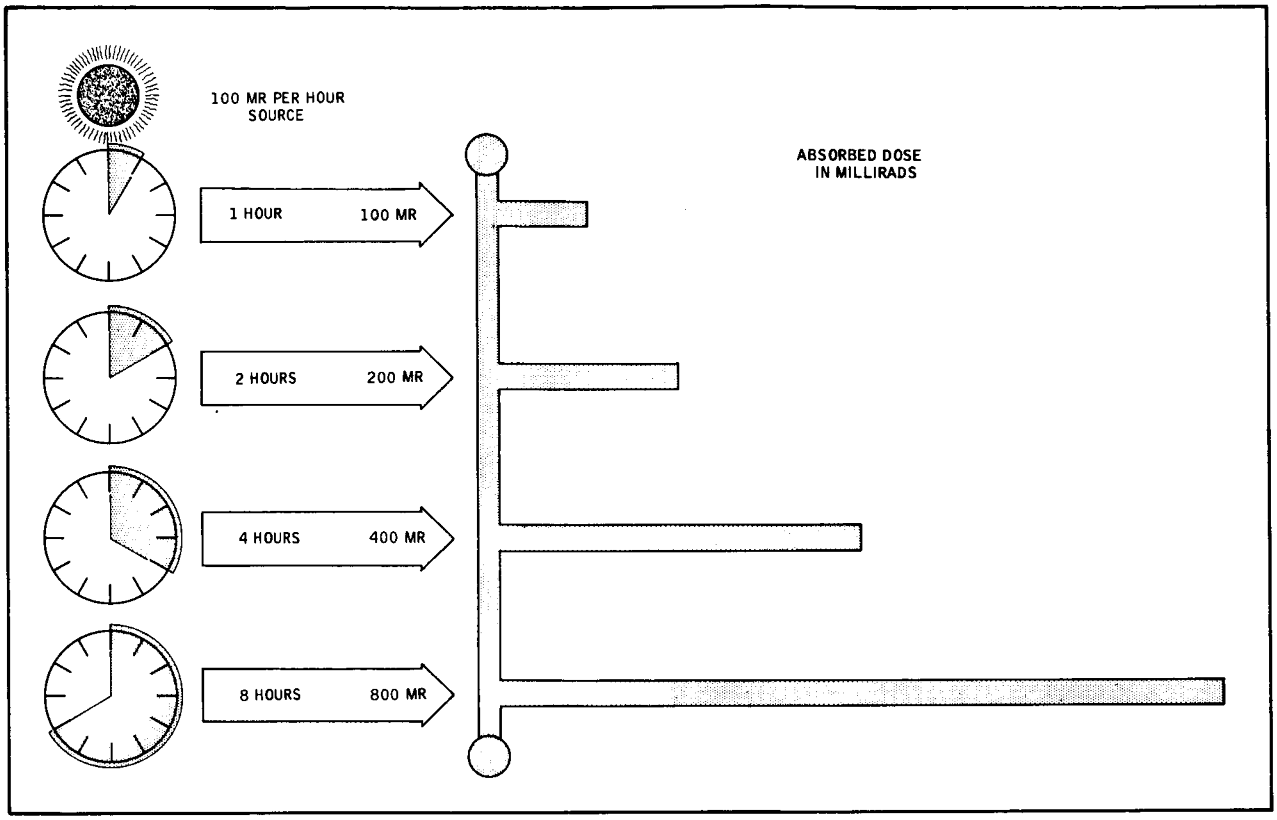


Figure 3-3. Effect of Time on Exposure

3-25. Distance. The effect that distance has on radiation exposure is tremendous. A distance of a few feet will determine whether a lethal or an insignificant dose is present. This is due to the inverse decrease of the radiation intensity with distance. That is, the intensity of radiation varies inversely with the square of the distance from the source as shown in figure 3-4.

If a source of radiation emitted 1000 roentgens of penetrating radiation at a distance of one foot, a person would receive 250 rems at two feet because the distance is double. From the inverse square law, it will be seen that this value is correct:

$$(\tfrac{1}{2}\text{ft})^2 = \tfrac{1}{4}\text{ft}; (\tfrac{1}{4}\text{ft})(1000\ \text{r}) = 250 \text{ rems at two feet.}$$

When the distance is extended to three feet, the dose in rems is reduced to $(1/3)^2$ or 1/9, to 111 rems. At a distance of 10 feet, the exposure would be $(1/10)^2$ or 1/100 of the radiation at one foot.

It should be noted, however, that the inverse square law applies to the degree that distances are large in relation to the size of the source. Commonly used radiation sources are generally quite small in size, so the inverse square law can be applied to distance in the immediate vicinity of the source. If, however, the source is large in size, such as a reactor, or the contamination of a large area, then the inverse square law does not apply until the distances are large in relation to the size of the source.

Compare the exposure rates in figure 3-4 with the probable dose effects in figure 3-2. Consider that the exposure rate at one foot is 1000 rems per hour and that a person remains at that distance for one hour. He will receive 1000 rems, and from figure 3-2 it is seen that this is a lethal dose. If he remains at two feet from the source for one hour, he will receive a dose of 250 rems. This puts him in the area of extreme illness and possible death. At three he would receive 111 rems; although death would not be expected, he could be quite ill for a time.

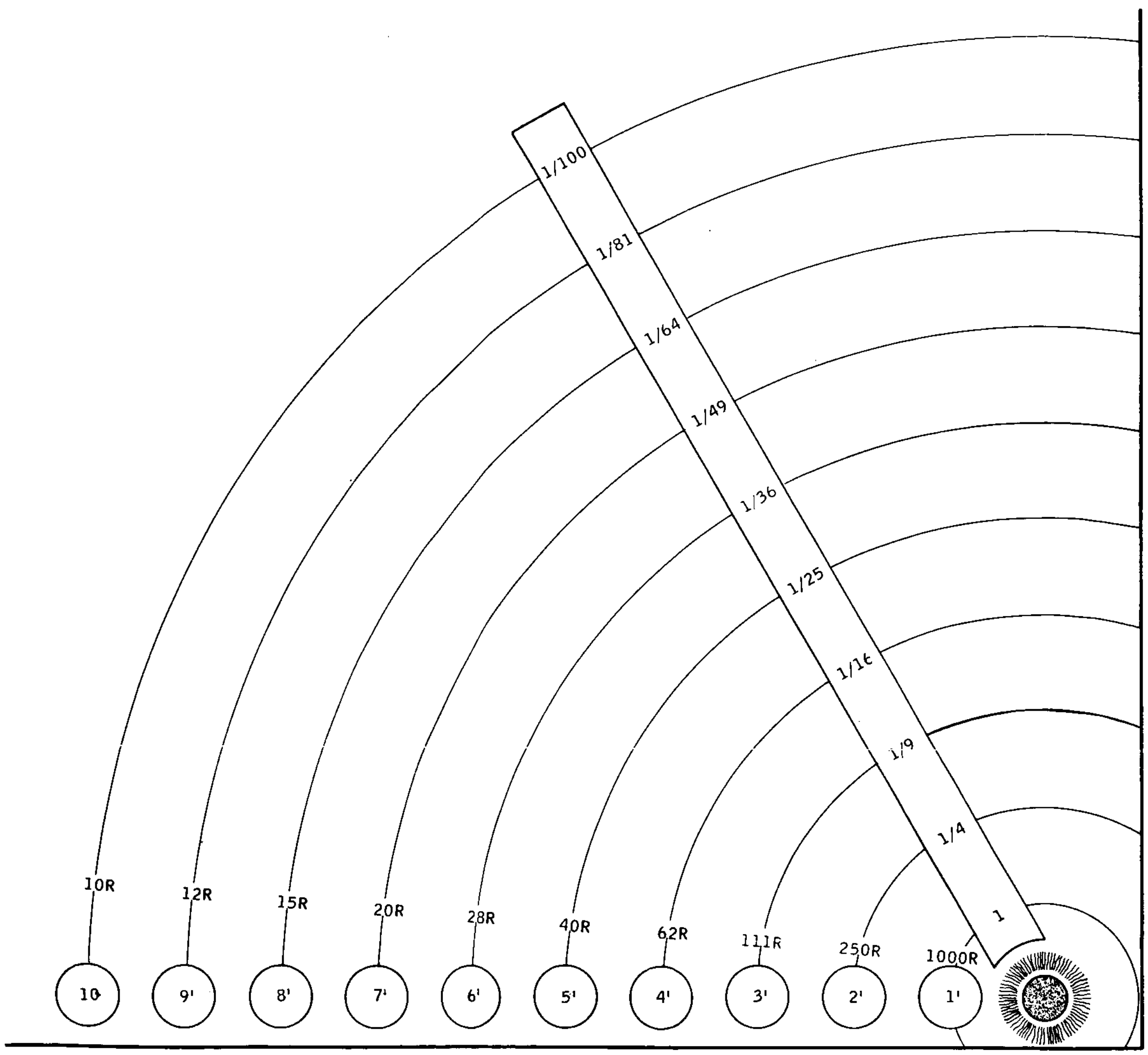


Figure 3-4. Effect of Distance on Radiation

At four feet, the intensity has decreased to the point that a person staying one hour in the area would probably not incur any noticeable effects. If the distance is extended out to 20 feet, a man would get only 2.5 rems within one hour, an inconsequential amount.

It is obvious, therefore, that a high ratio exists between distance and exposure. A small amount of distance can increase the safety factor of exposure many times over.

However, the converse is also true. As the distance to the radiation source decreases, the radiation rate will increase. For instance, at six inches, the radiation rate will go from 1000 r per hour to 4000 r per hour. From this it should be seen that distance is one of the most important factors in radiation safety. Always maintain the maximum distance between the body and the radiation source. Also, avoid touching materials which give off significant amounts of penetrating radiation as the safety factor of distance is completely eliminated in this case.

Table 3-2. Gamma Radiation Level at Three Feet from One Curie of Certain Radioisotopes.

Radioisotope	r/Hr	Radioisotope	r/Hr
Sodium 24	2.31	Iridium 192	0.61
Gold 198	0.30	Cobalt 60	1.59
Iodine 131	0.28	Zinc 65	0.36
Iron 59	0.77	Cesium 137	0.43

3-26. Shielding. As previously explained, the damaging effects of radiation come from the fact that the rays strike electrons in the body and knock them out of orbit. If this happens to a sufficient number of atoms, radiation damage is inflicted. If it is desired to decrease the number of rays striking the body, a material which has many electrons in its composition can be placed between the source and the body. The more electrons there are on the material, the more radiation will be stopped.

For instance, lead is a better shielding material than water because lead contains more electrons. Figure 3-5 shows the relative amounts of various shielding material required to reduce a particular gamma radiation by one half.

Considering that matter is mostly space, it is evident that no material is an absolute barrier to radiation. Regardless of the thickness, some radiation can penetrate the material without striking any electrons and, therefore, without being absorbed.

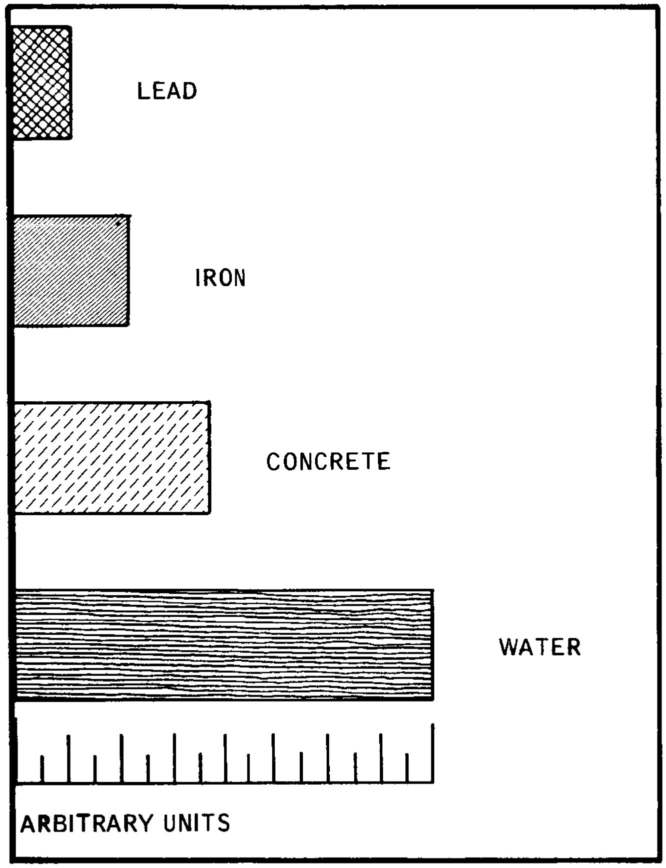


Figure 3-5. Relative Efficiency of Various Shielding Materials

3-27. Half-Value Layer. In calculating shielding for external radiation exposure, the amount of shielding required to stop all the radiation is not a desirable factor. The calculation that is needed and used is the amount of shielding required to stop one half the radiation of a given intensity. This is called the half-value layer.

Refer to figure 3-6. At the left side, two sources of radiation are shown. One source has a radiation level of 25,600 milliroentgens per hour and the other source 204,800, or eight times greater. With each successive layer of lead shielding that is added, the intensity of the radiation on the opposite side of the shielding decreases by one half. Seven half-value layers of shielding are required to bring the radiation level from 25,600 mr/h to 200 mr/h. Ten half-value layers are required to reduce the larger source to 200 mr/h. Although the larger source has a radiation level eight times the smaller source, only approximately 50 percent more shielding is required to reduce the radiation level to 200 mr/h on the other side.

This indicates that radiation shielding is not directly proportional to the amount of radiation being shielded. For example, a container for a 1000-curie source is not 1000 times heavier than for a one-curie source. Actually, the 1000-curie container is only 13 times heavier.

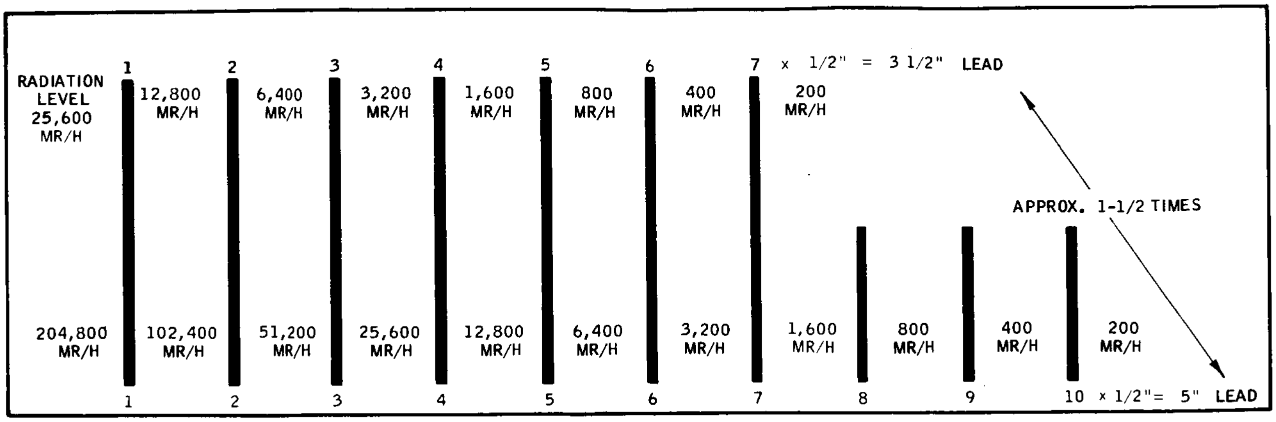


Figure 3-6. Effect of Successive Half-Value Layers of Shielding

The important factor in selecting the required number of half-value layers is the amount of radiation which escapes from the outside. This is the radiation to which personnel working in the area will be subjected. It is therefore necessary that all sources of penetrating radiation be properly shielded to bring down the radiation to a tolerable level. Naturally this applies to radiation sources in transit as well as a source stored in the laboratory.

3-28. INTERNAL RADIATION

Alpha and beta emitters present the greatest hazard as sources of internal radiation. Alpha radiation represents practically no external radiation problem; however, when an alpha emitter enters the body, the energy released is absorbed by the cells very close to the emitter. Since there is no dead layer of skin within the body to form a protective barrier for the living cells, alpha emitters inside the body can destroy living tissue.

Radioactive materials that emit beta particles represent an internal hazard similar to alpha emitters. If a beta emitter is deposited within the body, similar localized damage might result.

3-29. GENERAL

The internal radiation problem is much more complicated than the external radiation problem. Many more factors are involved, especially from the biological effects and the ways internal radiation may be incurred.

There are four possible ways to get radioactive materials into the body:

1. By breathing.
2. By swallowing.
3. Through breaks in the skin.
4. By absorption through the skin.

One of the more important factors concerning body damage is the length of time radioactive material remains in the body. A high percentage of inhaled substances is immediately exhaled. Swallowed materials, which are undissolved, are rapidly discharged through normal body functions. If a soluble material is breathed or swallowed, it will go into the circulatory system. The blood stream will then carry the material to various tissues and organs for acceptance or rejection.

The assimilation of materials by the body is a chemical process; therefore, the organs accept or reject materials by their chemical characteristics. If a material is rejected by all the organs, the blood stream will carry it to the kidneys for elimination from the body. However, if a material chemically resembles another, as radium does calcium, an organ or tissue might accept it. Since bone tissue seeks calcium, any radium entering the body could be distributed throughout the skeleton. Other organs and tissues tend to require particular elements. For instance, the thryoid gland requires iodine. The radioactivity of a material will have no effect on how an organ or tissue reacts to it.

Radioactive materials that are chemically inert, such as radon, will be absorbed very little as compared to radium. Most of the inhaled radon is immediately exhaled. The small amount remaining in the lungs and absorbed into the circulatory system will be eventually excreted from the body.

3-30. EFFECTS

The effects of internal radiation are related primarily to the type and quantity of the material, the radiosensitivity and essentiality of tissue, and the biological half-life of the material.

The biological half-life of a material is that time required for half the material to be excreted by the body. This time may vary from a few days to several years depending upon the body's chemical reaction to the material. The radiological half-life is combined with the biological half-life to obtain the effective half-life of the material in the body. Thus the damage inflicted upon the body will be proportional to the time the material remains in the body and which organs are affected.

3-31. PROTECTION

Certain handling processes of radioactive material may permit some of the material to become airborne where it can be breathed by personnel. A combination of protective measures is required to minimize the quantity of airborne particles and the degree of personnel involvements.

The first and simplest measures involve personal hygiene and safety rules which include the following:

1. Conscientious use of personal dosimeters.
2. Air monitoring program.
3. Use of respirators.

4. Exhaust systems.
5. Cover radioactive materials when they are handled or moved.
6. Avoid personal contact with radioactive materials; use handling devices when provided.
7. Do not smoke or eat in areas where radioactive materials are handled openly.
8. Do not use brooms for cleaning; use vacuum cleaners.
9. Wash up before eating or leaving the area.

These regulations will vary, of course, depending upon the nature and quantities of specific materials being handled. However, the rules governing each situation must be carefully followed to ensure a successful RADSAFE program.

In addition, contamination control, decontamination procedures, waste disposal, and accountability records will minimize the hazard of internal radiation.

3-32. AIR MONITORING PROGRAM

Laboratory air and air discharged from the laboratory will be monitored for radioactivity if there is any possibility of airborne contamination. Inhalation is the principal means by which airborne contaminants enter the body. The amount deposited in the body depends largely on the concentration in the air which is inhaled, the particle size of the contaminant, and the length of time the individual is exposed to the atmosphere. It is essential that the concentration of airborne radioactive substances be kept to a minimum. Maximum permissible concentrations (MPC) for various isotopes have been established, and to determine whether such standards are being met, routine air samples are collected and analyzed. Refer to Appendix B for a listing of these standards.

3-33. Stationary Monitors. Stationary monitoring devices will be used continuously to sample the contamination level of the air in a given area. Various sampling rates may be used as long as the collecting efficiency for the apparatus at that rate has been previously established. In cases of very low air concentrations, higher than normal sampling rates may be used, or samples may be selected over a long period.

3-34. Spot Sampling. Spot samples will be taken to indicate the concentration of airborne contamination at a precise time in a specific area. This method may also be employed to identify a specific source of contamination.

SECTION IV

OPERATIONAL PROCEDURES AND REQUIREMENTS

4-1. CUSTODIAN

The custodian shall be a person approved and licensed by the Atomic Energy Commission. He shall be qualified to receive, use, and have custody of radiation sources.

4-2. RESPONSIBILITIES

The custodian's responsibilities shall include:

1. Completing necessary forms for any procurement, transfer, or loan of radioactive sources and submitting them to the health physicist for approval by the RADSAFE committee.
2. Submitting an operational procedure for storage, handling, shipment, and use of any radioactive materials or sources of ionizing radiation in his custody to the health physicist for approval.
3. Maintaining records of all radiation sources in his custody, and submitting a list of them to the health physicist on request.
4. Conducting surveys and inspections as outlined in the Code of Federal Regulations and as prescribed by the health physicist.
5. Obtaining film badges from the Safety Office for all personnel exposed to radiation sources in his custody; ensuring that such badges are worn as prescribed in this section, and collecting and turning in film badges to the Safety Office for processing at the appropriate dates.

4-3. QUALIFICATIONS

The custodian shall be competent in the following areas:

1. Types of radiation.
2. Interactions of radiation with matter.
3. Health-physics instrumentation.
4. Techniques for handling radioactive materials.
5. Emergency procedure for controlling radioactive contamination.
6. Maximum permissible exposures.
7. Radioactive decay.
8. Specific activities associated with radiation sources.

If an individual is approved as a custodian, a written report stating his name, date of approval, and any quantity limitations will be forwarded to his Division Chief.

4-4. PROCUREMENT AND TRANSFER OF RADIATION SOURCES

The following procedures and regulations are applicable to all procurement of radioactive sources, whether procurement is to be by purchase, gift, or loan, and to all transfers of radioactive sources which will involve a change in the licensed person or location of the radioactive sources.

4-5. LICENSES

Licenses for radiation sources are of two types: general and specific. The general licenses provided in Part 30, Title 10, Code of Federal Regulations are effective without filing an application with the AEC or issuing licensing documents to particular persons. Specific licenses are issued to named persons upon applications filed pursuant to the regulations in Part 30 of Title 10.

4-6. General Licenses. A general license permits the licensee to transfer, receive, acquire, own, possess, and use radioactive material in the quantities specified in Part 30 of Title 10, without specific application to the AEC. No radioactive material shall be acquired by persons under KSC jurisdiction, or brought onto KSC premises, under either a general or specific license, without adhering to the following procedures.

4-7. Specific Licenses. Specific licenses designate the persons or organization and are issued for specific purposes provided that the purpose is authorized by the AEC. In addition, the licensee's equipment and facilities must be adequate to protect health and minimize danger to life or property. The applicant must be qualified by training and experience.

4-8. PROCEDURES

Persons or organizations who require radioactive materials will proceed as follows to request the material. The actions required to fulfill the requests are also outlined.

4-9. Requestor. The requestor shall complete the required requisition forms. These forms are available from the Safety Office.

4-10. Health Physicist. The health physicist shall receive the completed forms from the requestor, review them for completeness, and advise the RADSAFE committee of the proposed action. After approval or disapproval by the RADSAFE committee, the health physicist shall notify the requestor stating the action taken on the request. The original copy of this notice shall be filed for reference in the Safety Office. He shall then stamp and sign the appropriate forms for the RADSAFE committee and forward them to the Procurement Section. The health physicist shall maintain one copy of the requesting forms. He shall also provide delivery instructions when the source arrives.

4-11. Procurement Section. The procurement section shall receive the requisition forms and initiate the purchase in accordance with instructions from the health physicist. When the source arrives, the procurement section shall notify the health physicist and deliver the source in accordance with received instructions.

4-12. SOURCE ACCOUNTABILITY

It shall be a function of the Safety Office to maintain accurate records on all radiation sources at KSC. The custodian shall be responsible for accounting for all radiation sources at KSC. The custodian shall also be responsible for accounting for all radiation sources under his jurisdiction and reporting the locations of all sources to the Safety Office. Complete and accurate records of all radiation sources brought onto and taken off KSC premises shall be maintained.

4-13. STORAGE AND PROTECTION

Radioactive materials may be kept in normal storage provided the radiation intensity at one foot from the container does not exceed one milliroentgen per hour, and the containers are appropriately tagged. This tag must be plainly visible at all times. Radioisotopes of even low intensity should be stored at least 50 feet from undeveloped photographic film.

Radiation material with radiation intensities greater than one milliroentgen per hour at one foot must be stored in marked areas, storerooms, or buildings approved by the Safety Office for this purpose. These areas, storerooms, or buildings shall be locked and controlled to prevent entry of unauthorized personnel. The exterior of each building or storeroom and the boundary of each area shall be conspicuously posted with the appropriate signs. No loitering near storage areas, fences, or walls will be allowed. The area must be monitored at least once every 90 days. If the radiation limit is exceeded, the radioactive material will be rearranged to bring the radiation within tolerance, or the size of the storage area increased.

Containers of radioactive materials will not be opened by unauthorized personnel. Film badges will be worn by personnel working inside a storage area as prescribed by the Safety Office.

Storage areas will be secured against the unauthorized removal of materials.

4-14. FIRE HAZARDS AND CONTROL

The Fire Department shall be informed of the location of all radioactive sources. Fires occurring in areas that house radioactive materials, or materials that are in transit, present a hazard not only from the effects of fire but from the possible contamination of the area by the radioactive material. If a fire results in such an area, stay out of the smoke except for rescue purposes. Notify the Fire Department as well as the Safety Office of the fire and the involvement of radioactive material.

If it is necessary to enter the smoke, take all possible precautions to prevent the smoke from entering the throat and eyes. Those persons who have been exposed to these conditions will report to the health physicist for radiological monitoring and decontamination if necessary.

After the fire has been extinguished, do not permit any unauthorized personnel to enter the area nor permit any materials to be removed from the area. The health physicist will be responsible for monitoring the area and initiating any security measures or decontamination processes he deems necessary.

The extinguishing agent used on the fire will be governed by the type of fire (trash, oil, electrical, etc.). However, do not use unnecessary pressure that could inadvertently scatter the material. The main objective is to extinguish the fire as quickly as possible without scattering the radioactive material.

4-15. SHIPMENT OF RADIOACTIVE MATERIAL

All shipments of radioactive materials to or from KSC shall be directed through the Safety Office. Shipments via common carrier shall be governed by the applicable Interstate Commerce Commission regulations. Transportation of radioactive materials within KSC shall comply with procedures established by the Safety Office.

4-16. CLASSIFICATION OF RADIOACTIVE MATERIALS

Radioactive materials, Class D poisons, are divided into three groups according to the type of rays emitted at any time during transportation as follows:

a. Group I. Radioactive materials that emit gamma rays only, or both gamma and electrically charged corpuscular rays (alpha or beta, etc.).
b. Group II. Radioactive materials that emit neutrons and either or both the types of radiation characteristic of Group I materials.
c. Group III. Radioactive materials that emit electrically charged corpuscular rays only, or any other that is so shielded that the gamma radiation at the surface of the package does not exceed 10 milliroentgens for 24 hours at any time during transportation.

4-17. CONTAINERS

Shipping containers for radioactive materials must be so constructed that rupture of the inner liner will not result in a radiation hazard resulting in the vicinity of the container. The design and preparation of the container must be such that there will be no significant radioactive surface contamination of any part of the container. The smallest dimension of any outside shipping container must be not less than 4 inches.

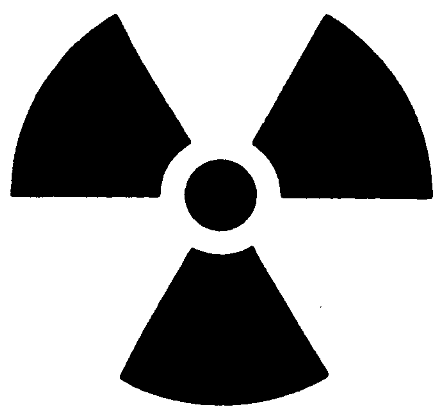
4-18. Packing and Shielding. The packing and shielding requirements for radioactive materials shipping containers are covered in detail in the Interstate Commerce Commission regulations for transportation of explosives and other dangerous articles. Any radioactive material that is to be transported by a common carrier must comply with these regulations.

4-19. SIGNS AND LABELS

The inside containers of packages must bear a durable, clearly visible label, bearing the standard radiation symbol (figure 4-1) and the following words:

CAUTION
RADIOACTIVE MATERIAL

CAUTION
RADIATION
AREA



AUTHORIZED ENTRANCE ONLY

CONTACT

RADIOLOGICAL MONITOR OR SUPERVISOR IN CHARGE

Figure 4-1. Radiation Warning Placard

Each outside container of radioactive material Group I or II, unless exempt by ICC regulations, must be labeled with a properly executed label as shown in figure 4-2.

Each outside container of radioactive material Group III, unless exempt by ICC regulations, must be labeled with a properly executed label as shown in figure 4-3.

Each container in which a quantity of any licensed material (other than natural uranium or thorium) is transported, stored, or used greater than the quantity of such material specified in Appendix C shall bear a radiation symbol and caution. Each container that houses ten times the quantity of natural uranium or thorium as specified in Appendix C shall also be so marked.

A label and marking shall not be required when the concentration in the container does not exceed that specified in Appendix B, Table 1, Column 2, or when the material is in laboratory containers and the user is present.

Where containers are used for storage, the required labels shall also state the quantity and type of material in the container and the date the quantity was measured.

4-20. GAMMA RADIATION

All outside shipping containers must be of such design that the gamma radiation will not exceed 200 milliroentgens per hour or equivalent at any point of readily accessible surface.

4-21. MAXIMUM SHIPMENT

No more than 40 units of radiation may be shipped in any one car, truck, or plane. One unit is defined as one milliroentgen per hour measured at a distance of one meter.

4-22. RECORDS AND RESPONSIBILITIES

The custodian or owner of the radioactive source shall prepare the required shipping forms and maintain records of the shipment. He shall also be responsible for preparing the source for shipment. The Safety Office shall have the prerogative to examine the source that has been prepared for shipment to ensure compliance with ICC regulations. The custodian shall notify the Safety Office of any planned shipments.

4-23. TECHNIQUES AND PRECAUTIONS FOR HANDLING RADIOACTIVE MATERIAL

It shall be the responsibility of each individual who has any contact or association with radioactive material to observe and practice the safety measures and procedures presented in this handbook. These exposure limits are established to maintain a level of exposure that will not exceed, during one's lifetime, a total that could have deleterious effects. However, the optimum goal is to work for a minimum of exposure.

Label For Group I Or II Shipment
By Common Carrier Other Than Air

Label For Group I Or II Shipment
By Common Air Carrier

Figure 4-2. Shipping Labels for Radioactive Materials Groups I and II

Label For Group III Shipment
By Common Carrier Other Than Air

Label For Group III Shipment
By Common Air Carrier

Figure 4-3. Shipping Labels for Radioactive Materials Group III

4-24. RADIATION-EXPOSURE LIMITS

The following radiation exposure limits shall apply to all personnel assigned to or under the jurisdiction of KSC.

No personnel shall receive a radiation exposure in any period of one calendar quarter in excess of the limits specified in Part 20, Title 10, Code of Federal Regulations that follow in part:

1. Whole body; head and trunk; active bloodforming organs; lens of eye, or gonads— 1-1/4 rem.
2. Skin of whole body— 7-1/2 rem.
3. Hands and forearms; feet and ankles (extremities)— 18-3/4 rem.

Without referral to the health physicist or the RADSAFE committee:

1. Whole body— 100 millirem/week.
2. Skin of whole body— 500 millirem/week.
3. Extremities— 1000 millirem/week.

With referral to the health physicist, but without referral to the RADSAFE committee:

1. Whole body— 100 millirem/day.
2. Skin of whole body— 500 millirem/day.
3. Extremities— 1000 millirem/day.

With referral to the health physicist and the RADSAFE committee and when warranted by unusual and extenuating circumstances:

1. Whole body— 100 millirem/day.
2. Skin of whole body— 1000 millirem/day.
3. Extremities— 2000 millirem/day.

4-25. PRECAUTIONS

The following precautionary measures are not intended to supersede but rather to supplement detailed operating and handling procedures that may be necessary for a particular mission.

4-26. Personal Dosimeters. All individuals working in laboratories, offices, rooms, or other areas where radioactive materials are in use, shall use a dosimeter such as a film badge. These will be submitted for processing on the first working day of each month. Personnel engaged in handling radioactive materials shall also wear waist-type badges to measure extreme exposure.

4-27. Surveys. All users of radioactive material shall perform a complete personal survey with a currently calibrated portable high-sensitivity survey instrument, capable of detecting the type of radiation emitted by the source, after each use of such material.

4-28. Protective Clothing. All users of radioactive materials shall wear protective clothing and gloves while actually engaged in using radioactive material. Laboratory coats, overalls, and gloves for use in handling shall be identified by the color yellow and a magenta radiation symbol.

4-29. Eating. No food or beverage shall be consumed in those areas where radioactive material is used or stored.

4-30. Storage. Each area and item of equipment where radioactive materials are used or stored shall be surveyed daily for contamination by the custodian with a suitable survey instrument.

4-31. Handling. Radioactive materials shall be handled with tongs, tweezers, or other handling devices whenever practicable. In no case shall sources of strengths greater than one microcurie be handled directly with the hands.

4-32. Waste. Waste radioactive material and contaminated material shall be placed in appropriate containers and properly sealed and labeled. They shall be disposed of in accordance with instructions in paragraph 4-54.

4-33. Incidents. All incidents which resulted or could have resulted in the radioactive contamination of personnel, area, or equipment, and/or overexposure of personnel shall be immediately reported to responsible supervision and to the Safety Office.

4-34. PERSONNEL MONITORING

Every person whose safety depends upon proper operating procedures rather than upon adequate shielding shall have upon his person a personnel meter at all times when exposure is possible. Personnel meters may be any one or a combination of the following types: (a) pocket ionization chamber; (b) pocket dose meter; and (c) photographic film meter.

Under some conditions other types of personnel meters may be used. Pocket ionization chambers with an alarm actuated after a pre-set exposure, crystal, or chemical dose meters may be used.

Personnel meters measure the exposure only at the point where they are worn, which should be the part of the body expected to receive the greatest exposure.

4-35. PRECAUTIONS

Film badges shall be worn on the front of the body between the waist and the neck. Personnel shall not deliberately expose any badge to radiation. Personnel film badges shall not be used as experimental detectors, nor shall the film pocket in the badge be rearranged or abused.

4-36. RECORDS

Each licensee shall maintain records showing the radiation exposures of all individuals for whom personnel monitoring is required (paragraph 4-34). Such records shall be kept on Form AEC-5 or on records containing the information required on Form AEC-5. Doses entered on the form shall be for periods of time not exceeding one calendar quarter.

Records of individual radiation exposure must be maintained for the length of time determined by Part 20 of Title 10.

4-37. REPORTS OF THEFT OR LOSS OF LICENSED MATERIAL

Immediately after any loss or theft becomes known of licensed material in such quantities and under such circumstances that it appears to the licensee that a substantial hazard may result to persons in unrestricted areas, the licensee shall make a report to the AEC. The report shall be by telephone and telegraph to the Director of the appropriate Atomic Energy Commission Regional Compliance Office.

4-38. NOTIFICATION OF INCIDENTS

Each licensee shall immediately notify the Director of the appropriate Atomic Energy Commission Regional Compliance Office by telephone and telegraph of any incident involving byproduct, source, or special nuclear material possessed by him which may have caused or threatens to cause:

(1) Exposure of the whole body of any individual to 25 rems or more of radiation; exposure of the skin of the whole body of any individual to 150 rems or more of radiation; or exposure of the feet, ankles, hands, or forearms of any individual to 375 rems or more of radiation.
(2) The release of radioactive material in concentrations which, if averaged over a period of 24 hours, would exceed 5,000 times the limits specified for such materials in Appendix B, Table II.
(3) A loss of one working week or more of the operation of any facilities affected.
(4) Damage to property in excess of $100,000.

Each licensee shall within 24 hours notify the Director of the appropriate Atomic Energy Commission Regional Compliance Office by telephone and telegraph of any incident involving licensed material possessed by him which may have caused or threatens to cause:

(1) Exposure of the skin of the whole body of any individual to 30 rems or more of radiation; or exposure of the feet, ankles, hands, or forearms to 75 rems or more of radiation.
(2) The release of radioactive material in concentrations which, if averaged over a period of 24 hours, would exceed 500 times the limits specified for such materials in Appendix B, Table II.
(3) A loss of one day or more of the operation of any facilities affected.
(4) Damage to property in excess of $1,000.

4-39. RADIATION EXPOSURE REPORT TO FORMER EMPLOYEES

At the request of a former employee, each licensee shall furnish to the former employee a report of the former employee's exposure to radiation as shown in records maintained by the licensee. Such reports shall be furnished within 30 days from the time the request is made; shall cover each calendar quarter of the individual's employment involving exposure to radiation, or such lesser period as may be requested by the employee. The report shall also include the results of any calculations and analyses of radioactive material deposited in the body of the employee. The report shall be in writing.

4-40. REPORTS OF OVEREXPOSURES AND EXCESSIVE LEVELS AND CONCENTRATIONS

In addition to any notification required, each licensee shall make a report in writing within 30 days to the Director, Division of Licensing and Regulation, Washington 25, D. C., with a copy to the Director of the appropriate Atomic Energy Commission Regional Compliance Office, of (1) each exposure of an individual to radiation or concentrations of radioactive material in excess of any applicable limit in this part or in the licensee's license; (2) any incident for which notification is required, and (3) levels of radiation or concentrations of radioactive material (not involving excessive exposure of any individual) in an unrestricted area in excess of ten times any applicable limit set forth in this part or in the licensee's license. Each report required under this paragraph shall describe the extent of exposure to radiation or to radioactive material; levels of radiation and concentrations of radioactive material involved and the cause of the exposure, levels, or concentrations. Corrective steps taken or planned to assure against a recurrence shall also be reported.

4-41. VISITOR EXPOSURE CONTROL

All visitors to areas where exposure to radiation is possible will be provided with personnel meters. The visitor's name, purpose of visit, organization represented, and any other data required by the Safety Office will be submitted. A record of the visit and amount of exposure will be kept in the Safety Office. Visits into radiation areas will be limited to those deemed essential by the responsible supervision.

4-42. EMERGENCY PROCEDURES FOR CONTROL OF RADIOACTIVE CONTAMINATION

Incidents involving radioactive contamination will probably be involved in one of the following or similar type emergencies:

a. Explosion.
b. Fire.
c. Laboratory spill.
d. Unscheduled impact.
e. Vehicle accident.

The nature, quantity, area, personnel involvement, and type of contamination will dictate the specific procedures to be followed for an incident. However, the following general procedures should apply in part for any incident:

a. Evacuate personnel from the area and do not permit entry by unauthorized personnel.
b. Report the incident to the health physicist.
c. Avoid smoke, dust, mist, or other visible airborne particles.
d. Refer involved personnel to the health physicist for monitoring and decontamination.
e. The areas and equipment involved will be monitored and decontaminated as required.

4-43. CONTAMINATION OF PERSONNEL

4-44. Decontamination Procedures.

Thorough washing with soap and water is the best general method for decontamination of the hands and other parts of body, regardless of the contaminant. If the contamination is localized, it may be more practical to mask off the affected area and cleanse with swabs, before risking the danger of spreading the contaminant by general washing.

If the exact nature and characteristics of the contaminant are known, it may be more effective to immerse the area, if practicable, in a suitable reagent immediately after contamination. Follow with a thorough washing in tepid water with a mild soap and thorough rinsing in clean water. Common household detergents, as well as specific ones, and wetting agents may also prove useful for particular types of contaminants. The skin may become sensitive following the repeated use of detergents to the same area; therefore, care should be taken to avoid indiscriminate use of detergents. The use of organic solvents must be avoided to minimize the probability of radioactive materials penetrating the pores of the skin.

The recommended procedures for general handwashing are:

a. Wash for not less than two minutes, nor more than three minutes with a mild, pure soap in tepid water, thoroughly covering the entire area. Give particular attention to the areas between the fingers, around nails, and the edges of the hands. Do not use highly alkaline soaps or abrasives. Rinse thoroughly and repeat, as monitoring indicates, until the desired degree of decontamination is achieved, but do not exceed three or four repetitions.
b. If the above procedure fails to remove the contamination, scrub the hands with a soft brush using a heavy lather and tepid water. Wash the hands three times, including rinses, within eight minutes. Six minutes of this time should be devoted to scrubbing. Apply light pressure only with the brush so as not to scratch or abrade the skin. Rinse thoroughly and monitor.
c. Apply hand cream to prevent chapping.

Chemicals may be used for cleansing other parts of the body or hands, if the previous procedures do not successfully remove the contamination. The two processes in general used are listed below:

a. Apply a liberal quantity of titanium dioxide paste to the hands. Prepare the paste by mixing precipitated titanium dioxide with a small amount of lanolin into a thick slurry. Do not permit it to dry. Work this paste over the affected surface and adjacent areas of the skin for at least two minutes. Use water sparingly to keep the paste moist. Rinse with warm water, and follow by thorough washing with soap, brush, and water. Be sure that no paste is allowed to remain around the nails; monitor. Repeat the entire process if necessary.

b. Mix equal volumes of a saturated solution of potassium permanganate and 0.2 N sulfuric acid. Pour this over the wet hands. Rub the entire surface with a hand brush for not more than two minutes. (Note: this application will remove a layer of skin if allowed to remain in contact with the hands too long; consequently, the time stated here should not be exceeded for any single application.) Be sure that all areas are thoroughly covered. Rinse with warm water and proceed as follows:

Apply a freshly prepared 5 percent solution of sodium acid sulfite ($NaHSO_3$) in the same manner as above; use a hand brush and tepid water for not more than two minutes. Wash with soap and water and rinse thoroughly.

The above procedure may be repeated several times as long as the permanganate solution is not applied for more than two minutes during any one washing. Applications to parts of the body other than the hands may be facilitated by the use of swabs steeped in the solutions. Apply hand cream after washing.

4-45. Permissible Levels of Contamination. The danger resulting from contamination of the hands or other parts of the body depends primarily on the type of radioisotope and level of activity and the condition of the contaminated skin. A person should not be permitted to work with radioisotopes if there are open cuts or abrasions on the body. After the body has been washed as explained in 4-44, a satisfactory maximum permissible exposure due to spot skin contamination (group I of figure 4-4) is 1 mrem/hr average as measured in a small volume of air (in a thin layer) above any 2-square inch area of the body. If a gamma-emitting isotope is the contaminant on the body, an approximate reading of 1000 counts per minute with a Geiger counter (with a flat plate area of 2-square inches) placed as close as possible to the contaminated area is equivalent to 1 mrem/hr average. A thin-walled Geiger counter may be used to measure low-energy beta-emitting contaminants such as C14 or C35. In case of contamination by radioisotopes of group III, the measurable radiation at the surface of the body should be reduced to as near background as possible and the maximum permissible level of contamination is 0.1 mrem/hr (less than 100 counts per minute).

If the body is generally contaminated, and especially if contamination is in the eyes or on the gonads, special efforts should be made to reduce the contamination level. If the body is entirely covered with contamination, it should be reduced to 0.1 mrem/hr (less than 100 counts per minute), regardless of the group of radioisotopes involved.

GROUP I - SLIGHT HAZARD

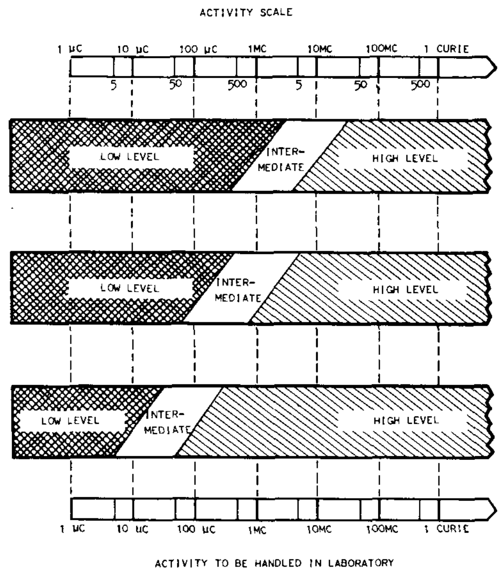
*Na24, K42, Cu64, *Mn52, *As76, As77, Kr85, *Hg197

GROUP II - MODERATELY DANGEROUS

H3, C14, P32, *Na22, S35, Cl36, *Mn54, *Fe59, *Co60, Sr89, *Cb95, *Ru103,Ru106, Te127, Te129, I131, *Cs137, *Ba140, *La140, Ce141, Pr143, *Nd147, *Au198, *Au199, Hg203,205

GROUP III - VERY DANGEROUS

Ca45, Fe55, Sr90, Y91, *Zr95, Ce144, Pm147, Bi210



NOTES

Selected radioisotopes grouped according to relative radiotoxicity, with the amounts considered as low, intermediate, or high level, in laboratory practice. These groups are not to be confused with ICC groupings for regulation of shipments.

Effective radiotoxicity is obtained from a weighting of the following factors:
- Half-life.
- Energy and character of radiations.
- Degree of selective localization in the body.
- Rates of elimination.
- Quantities involved and modes of handling in typical experiments.

The slant boundaries between levels indicate border-line zones, and emphasize that there is no sharp transition between the levels and the associated protection techniques.

The principal gamma-emitters are indicated by asterisk (e.g., *Na24). The above level system does not apply to the hazards of external irradiation.

Figure 4-4. Relative Hazards from Absorption of Selected Radioisotopes into the Body

4-46. WOUNDS

Extreme precautions must be taken to avoid cuts or puncture wounds. This is especially true when working with isotopes of groups II and III, and intermediate or high level isotopes. If the skin is broken in accidents while working with radioactive substances, immediate action should be taken to remove possible contamination. Immediately wash the wound under large volumes of running water (within 15 seconds) and spread the edges of the gash to permit flushing action by the water. Light tourniquet action to stop venomous return (but not to restrict arterial flow) may be desirable to stimulate bleeding. Report all wounds to the responsible medical officer or health physicist as soon as emergency precautions have been taken.

4-47. CLOTHING

Issue clothing and personal clothing worn in radioactive areas which may have been subjected to contamination, shall be monitored routinely each day, or when one's work with the radioactive material is finished. Articles which show contamination shall be left in the work area or other designated areas, until they have been decontaminated, or until the activity has decayed to a safe level. For persons working with isotopes, consideration shall be given to the provision of change rooms where issue clothing (or personal clothing, if necessary) may be discarded. Under no circumstances shall contaminated clothing be worn into clean areas. Where change rooms are not provided, a centrally located shower should be provided for use of personnel working with intermediate and high levels of activity of isotopes in all groups. Personnel should be instructed in the use of this shower.

All clothing that is known or suspected of being contaminated shall be placed into containers that are provided for that purpose (groups II and III, and intermediate or high levels of activity of group I). The clothing shall first be marked by the user with his name, the date, and the nature of the contamination. The clothing shall then be monitored to determine the degree of contamination, held for storage and decay if the contaminant is short lived, laundered if possible, or disposed of in a proper manner.

All handlers engaged in monitoring and decontamination must be provided with protective coats and suitable gloves.

4-48. Decontamination Procedures. Decontaminated clothing should not be released to public laundries unless the contamination is below permissible levels and of short half-life. Usually there is no problem in this regard when working at low levels of activity. For clothing contaminated with radioactive materials having short half-lives, storage is recommended until the contamination is reduced to a safe level; care must be taken, however, to prevent airborne contamination from clothing placed in storage.

If storage or laundering is not practical, it is recommended that contaminated clothing be disposed of when the contamination is above permissible limits.

Where special laundering facilities are available, each garment shall be monitored to determine the extent of the contamination. In general, this monitoring for hard beta and gamma emitters may be accomplished by closely scanning each garment with a Geiger-Muller counter (30-mg/cm^2 thickness) with a flat plate area of about 2 square inches, and then measuring the areas of highest activity. When monitoring reveals that clothing is contaminated above the permissible levels, laundering may then be attempted. When several levels of contamination are found, it will be desirable to segregate the clothing according to activities (e.g., low, medium, or high) and perform separate laundering operations.

In the selection of any decontamination procedures, the chemistry of the contaminant should be considered. If this is not feasible, one of the following procedures, which have been used in the decontamination of clothing, may be desirable

Garments in each of these classifications should be laundered as follows:

Class 1. (For low activity, less than 1000 counts per minute for groups I and II, and less than 100 counts per minute for group III). Release for ordinary laundering.
Class 2. (For medium activity, above the activities of Class 1 and up to 10,000 counts per minute); hot rinse, hot rinse, hot solution of 3-percent citric acid wash, hot rinse, hot suds, hot rinse, hot 1.5-percent citric acid wash, three hot rinses, cold rinse, cold rinse, starch if desired, monitor, and repeat if necessary.
Class 3. (For high activity, greater than 10,000 counts per minute) procedures identical to those of Class 2, but laundering should be performed separately from garments of a lower classification.

After garments have dried, check each by the procedure established for original monitoring for decontamination. If the laundered garments do not fall in Class 1, rewash.

Care should be taken to prevent laboratory floors and plumbing from becoming contaminated beyond safe levels. Recommended procedures for their decontamination may be found in subsequent sections.

Rubber gloves and other rubber goods usually decontaminate readily. Such items should first be washed with plenty of suds and hot water. If this does not prove effective, rubber items should be washed in diluted nitric acid. This should be followed by a wash using scouring powder and a thorough rinse in running tap water. Dry with paper toweling, which should be discarded in the dry active-waste can.

Leather goods cannot be easily decontaminated. Hence, shoe covers or rubber overshoes should be worn for protection.

Clothing that cannot be successfully laundered or held for storage shall be regarded as dry radioactive waste and disposed of in accordance with recommended procedures.

"Assault masks" may be decontaminated by washing with soap, a hot 20-percent solution of sodium citrate, or other similar agents.

4-49. Permissible Levels of Contamination. The levels of maximum permissible contamination applied to clothing are:

For groups I and II, 1 mrem/hr for beta or gamma radiation measured as the average near the surface of the garment. This corresponds to approximately 1000 counts per minute when a Geiger-Muller counter having a flat plate area of 2 square inches is placed against the garment. (A thin-window Geiger-Muller tube must be used to measure soft beta.)

For group III the radiation level should be close to background (less than 100 counts per minute of beta and/or gamma).

In applying the above levels to the body or clothing, it is usually assumed that most of the radioactivity is contained in a few small spots and not uniformly distributed over the entire body or garment.

4-50. CONTAMINATION OF LABORATORY TOOLS AND GLASSWARE

It is desirable to monitor all laboratory tools and glassware before use, unless it is known with certainty that such items are new stock issue. At the same time, care should be taken that no equipment, not immediately necessary to the operations being performed, is brought into the active area. Handling-tools and equipment, when used, shculd be placed in nonporous metal trays or pans, which are located away from the actual working space. It is desirable to line such trays and pans with absorbent disposable paper, which is changed frequently. Auxiliary containers, blotters, and covers shall always be used where danger of spills and contamination of the person or equipment is possible (all groups and levels). Contaminated equipment, or equipment that has been used and is suspected of contamination, should be isolated in designated areas in the laboratory or in suitable storage spaces. A "radiation hazard" label, sticker, or stencil shall be affixed on all containers actually containing, or contaminated with, radioactivity until cleaning can be performed. The use of temporary labels is preferred over permanent stenciling on glassware. Monitoring of equipment and tools shall be a routine procedure following their use, and before release to stock (all groups and levels).

4-51. Decontamination Procedures. In the most general terms, decontamination of tools and glassware is undertaken to reduce the hazard to personnel using them or to remove radioactive contaminants that might hinder laboratory experimentation.

Decontamination methods fall into two broad classifications: corrosive and noncorrosive. It is always desirable to use a noncorrosive method, yet this is seldom practical, since removal of the surface layers of material is more effective in putting absorbed ions back into solution than the very slow processes of ion exchange or desorption by noncorrosive methods.

Some of the more common decontamination procedures, involving both corrosive and noncorrosive methods, are given.

All glassware should be washed with acid (chromic acid cleaning solution or concentrated nitric acid) and rinsed, as a routine procedure following use (all groups and levels of activity). All metal tools employed should be surveyed to detect possible contamination (all groups and levels of activity). The use of acid on metal tools may unnecessarily corrode them, causing greater difficulty in future decontamination procedures. Some elements (e.g., iodine) will become volatile upon reaction with acids; in such cases, it may be desirable first to attempt decontamination with detergents.

Equipment that is found to be contaminated after the initial treatment shall be stored in an isolated location, possibly in a hood with adequate exhaust or under water, until more thorough decontamination procedures may be applied. If it is necessary to dismantle any equipment prior to decontamination procedures, a careful survey should be made during the operation. Contaminated equipment shall not be released from control of the laboratory for repair, or any other purpose, until the level of activity has been reduced to a safe limit. Where the half-life of the contaminating element is short, it may be desirable to store tools and glassware for decay of activity rather than to attempt decontamination. In many cases, if the items are cheap or easily replaced, it may be simpler to dispose of such equipment in a recommended manner and replace with new apparatus.

Equipment that is contaminated with radioisotopes of groups II or III, or with long-lived isotopes that cannot be satisfactorily decontaminated, must be regarded as radioactive waste and disposed of in a proper manner.

Cleaning of contaminated glassware and tools should be done by designated handlers in a well-ventilated hood set aside in the laboratory for that purpose, or in controlled areas away from the active work laboratories.

Glass and porcelain articles may be cleaned with mineral acids, ammonium citrate, trisodium phosphate, cleaning solution (chromic acid) or ammonium bifluoride. When the glaze is broken on porcelain, or when active solutions are heated to extreme dryness in glass, decontamination is very difficult, and usually it is more convenient to replace items so treated.

Metal objects may be decontaminated with dilute mineral acids (nitric), a 10-percent solution of sodium citrate, or ammonium bifluoride. When all other procedures fail for stainless steel, use hydrochloric acid. This is a good decontaminant, for the reason that it removes some of the surface; however, this procedure results in etching of the stainless steel, which makes it less desirable for future use. With brass, it has been demonstrated that brass polish is an excellent decontaminant. Plastics may be cleaned with ammonium citrate, dilute acids, or organic solvents.

It should be noted that the effectiveness of a decontaminating process is, for all practical purposes, complete at the end of the second repetition of the process. If necessary, other methods should then be considered for further decontamination.

Laboratory equipment should be surveyed for residual contamination following decontamination procedures. Decontamination seldom exceeds 99.9 percent efficiency and usually runs about 98 to 99.5 percent. If the residual contamination indicates that the level of activity is still greater than that specified as permissible, equipment shall be regarded as radioactive waste. Glass equipment of this nature should be broken to prevent accidental return to stock or other use.

Glassblowing, welding, brazing, soldering, etc. should never be permitted on equipment contaminated with radioactive materials unless it is done in specially ventilated facilities, and unless special techniques are used to prevent the inhalation of radioactive dust and fumes.

4-52. Permissible Levels of Contamination. The permissible levels of contamination given in paragraph 4-45 are also applicable to laboratory tools and glassware.

4-53. TAGGING LIMITS AND PROCEDURES

Items and equipment and components of equipment, that are to be sent to a decontamination area, are to be handled generally as follows:

a. Tag each piece to be decontaminated.
b. The tag should contain the following information:
    1. Type and amount of contamination.
    2. Permissible level of contamination.
    3. Limitations of decontamination procedures (e.g., do not immerse in or scrub with water, do not scrub with acid solutions, etc.).
    4. Using organization.
    5. Tag number.
c. If the contaminated pieces are to be moved through a clean area, seal them in polyethylene bags or wrapping to prevent contamination of the clean area as well as the transporting vehicle.

Maintain a record of each piece sent out for decontamination. These records should show date shipped, tag number, and description.

4-54. DISPOSAL OF RADIOACTIVE MATERIAL

Two factors which will be involved in any decision relating to methods of disposal are safety and convenience. If the materials involved are of small quantity, have relatively short half-lives, and the radiation level is low, such materials may be disposed of by flushing into the drainage or sewage system. If the quantities and radiation level are too great for this method, then others must be used.

4-55. LOW-LEVEL WASTE

Land burial of packaged low-level radioactive wastes will be permitted at AEC sites located near Oak Ridge, Tennessee, and Idaho Falls, Idaho. Arrangements for land burial of packaged low-level wastes should be made with the AEC's Oak Ridge Operations Office, for land burial at Oak Ridge, and with the Idaho Operations Office for land burial at Idaho Falls. Requests for information concerning terms and conditions of such arrangements should be directed to:

Manager of Operations, P. O. Box E, Oak Ridge, Tennessee.

Manager of Operations, P. O. Box 1221, Idaho Falls, Idaho.

The types of packaged low-level waste to which this applies include such items as broken glassware, paper wipes, rags, ashes, animal carcasses, laboratory paraphernalia, etc.

Shipments of packaged low-level waste must comply with ICC regulations governing package and shipment of Class D poisons.

4-56. Liquid Waste. AEC license holders may dilute and discharge liquid waste into the sewage system provided the following conditions are met:

1. The quantity released, if diluted by the average daily quantity of sewage released by the licensee, will not exceed the value for the maximum permissible concentration for that element listed in Appendix B.
2. The quantity of material released in any one month shall not exceed that which would result in an average concentration in excess of the values listed in Appendix B.
3. The average concentration of any radioactive material released into an uncontrolled area shall not exceed, at that point at which the licensee looses effective control, the value given in Appendix B.

Ground disposal of low-level and intermediate-level waste may be practical. However, the following factors must be considered in any ground disposal program:

a. Chemical, physical, and radiological properties of the waste.
b. The allowable concentration in water supplies of each isotope in the waste.
c. The effectiveness and permanence of retention of the active material on the soil.
d. The possibility that the absorbed material may be leached from the soil by rain, or displaced by ions added by subsequent waste.
e. The location and direction of movement of the ground water and the amount of dilution afforded by the ground water.

4-57. Solid Waste. Solid waste may be disposed of by burial, incineration if combustible paper, rags, or wood, or by remelting if metallic. The Safety Office shall select the procedure.

4-58. DISPOSAL IN THE OCEAN

Disposal of all packaged waste shall be in regions where water depths exceed 1000 fathoms. Containers for packaged disposal shall be designed, constructed, and filled in such a way as to insure that the package:

a. Cannot be easily damaged or broken, and will reach the bottom without appreciable loss of contents.
b. Is free of voids.
c. Has a minimum average density of 1.2 g/cm^3, or ten pounds per gallon.
d. Has sufficient shielding for safe storage, shipment, and handling.
e. Is of a size and shape to be handled quickly and conveniently.

4-59. HIGH-LEVEL WASTE

All high-level waste will be shipped to an AEC approved facility for burial. Shipment and shipping will be in accordance with ICC regulations for such materials.

4-60. RECORDS

Complete records shall be maintained on all disposals. Records shall include quantity, type, location, and other pertinent information of the disposal.

SECTION V

PERMISSIBLE DOSES FROM EXTERNAL RADIATION

5-1. BASIC PERMISSIBLE WEEKLY DOSES

5-2. LONG-TERM EXPOSURE TO X-RAYS

Appropriate radiological experience is based largely on whole-body exposure of personnel to the X-rays used in diagnosis and therapy (up to 250 kv). Under these conditions, the skin always receives the highest dose, in roentgens, and certain deep-seated tissues the lowest. The bloodforming organs, being widely distributed, receive intermediate average doses. The following paragraphs list the basic permissible weekly doses for the various body organs.

5-3. Bloodforming Organs. It is recommended that for whole-body exposure to X-rays for an indefinite period of years, the basic permissible weekly dose in the bloodforming organs be 100 mr.

5-4. Skin. It is recommended that for whole-body exposure to X-rays for an indefinite period of years, the basic permissible weekly dose in the skin be 500 mr.

5-5. Gonads. It is recommended that for exposure to X-rays for an indefinite period of years, the basic permissible weekly dose in the gonads be 100 mr.

5-6. Lens of the Eye. It is recommended that for exposure to X-rays for an indefinite period of years, the basic permissible weekly dose for the lens of the eye be 100 mr.

5-7. Other Organs and Tissues. The spatial distribution of radiation in figure 5-1 represents the basic permissible weekly tissue doses from the surface of the main portion of the body in terms of RADS as well as roentgens, in the case of whole-body exposure to X-rays.

5-8. LONG-TERM EXPOSURE TO IONIZING RADIATION

The basic permissible weekly tissue doses for exposure to any ionizing radiation for an indefinite period of years, shall be as follows:

Skin	500 millirems
Bloodforming organs	100 millirems
Gonads	100 millirems
Lens of the eye	100 millirems
Other organs and tissues	(See accumulated dose distribution in figure 5-2)

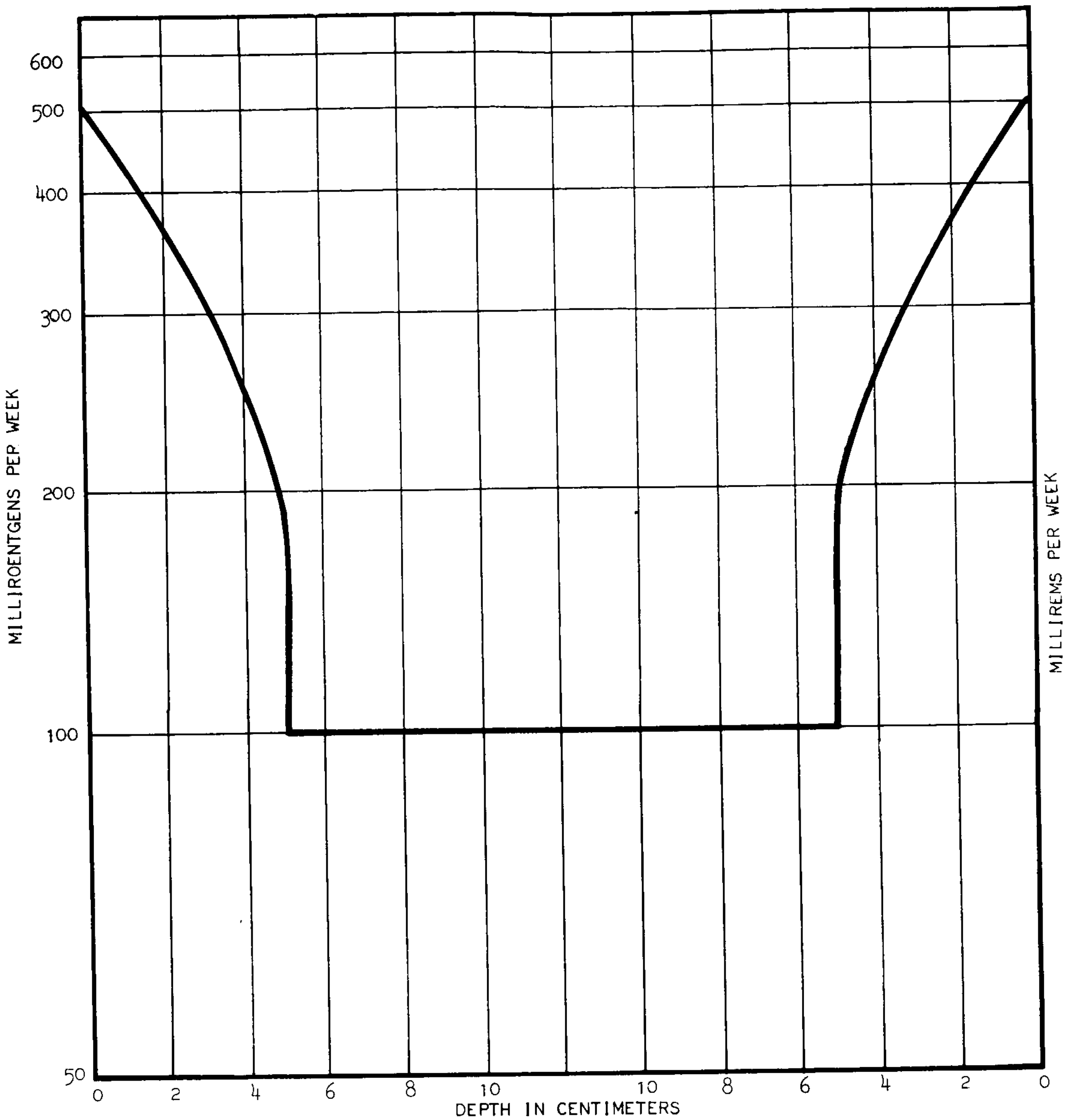


Figure 5-1. Basic Permissible Dose Distribution in Main Portion of the Body

5-9. ACUTE EXPOSURES

Refer to paragraph 3-13 for the probable physical effects of a single exposure to radiation delivered within a 24-hour period. The health physicist and medical officer will be responsible for the required treatment in such an incident.

5-10. EMERGENCY EXPOSURES

A person may be exposed only once in his lifetime to an accidental or emergency dose of 25 rems to the whole body, or a major portion of the body. Such an exposure need not be included in the determination of the radiation exposure status of that person.

5-11. MODIFYING FACTORS

5-12. Weekly Dose Fluctuations. In exceptional cases it may be necessary for a person to receive in one week more than the basic permissible weekly organ doses; then the unit of time may be extended to 13 weeks. In this case the dose in any organ accumulated during a period of seven consecutive days must not exceed the respective basic permissible weekly dose by more than a factor of five and the total dose accumulated in any organ during a period of any 13 consecutive weeks must not exceed the respective basic quarterly doses as listed in paragraph 4-24.

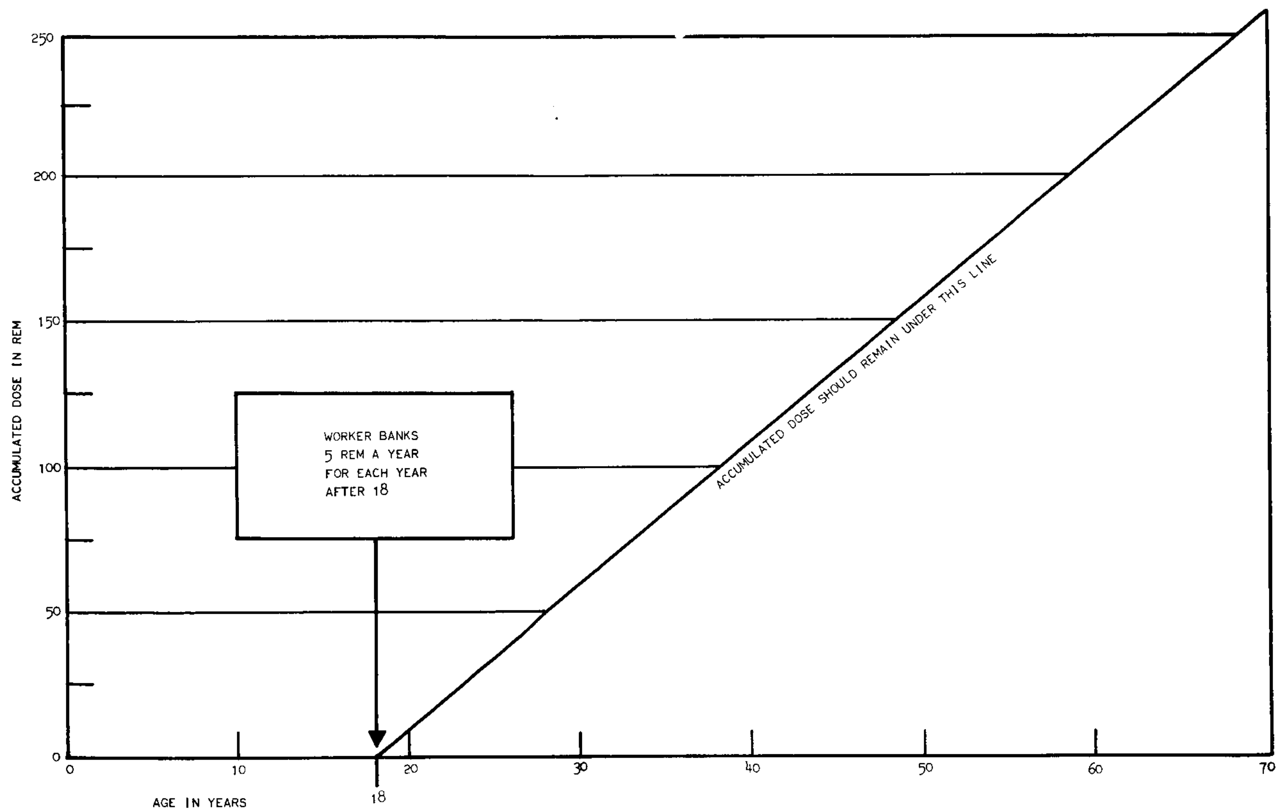


Figure 5-2. Exposure Banking Chart for Radiation Workers.

5-13. NONOCCUPATIONAL EXPOSURE

Personnel who work in areas close to X-ray installations and other sources of radiation, although not connected with radiation work, may be subject to exposure. The radiation levels in these areas will be maintained as prescribed in paragraph 4-2.

APPENDIX A

GLOSSARY OF TERMS

AIRBORNE RADIOACTIVE MATERIAL

Any radioactive material present in the air in solid or liquid form, as dust or mist, and in gaseous form as fumes, vapor, or gas.

ALPHA PARTICLE

A positively charged particle emitted from a nucleus of certain naturally radioactive substances, such as radium or uranium. It is composed of two protons and two neutrons. It is identical in all measured properties to the nucleus of a helium atom.

ALPHA RAYS

A synonym for alpha particles. A radiation which is strongly ionizing and weakly penetrating. The rays are deflected by electric and magnetic fields and consist of doubly charged helium ions.

ANEMIA

A deficiency of the blood as a whole, or the deficiency in the number of red corpuscles or of the hemoglobin.

ATOMIC MASS

The mass of a neutral atom of a nuclide. It is usually expressed in terms of the physical scale of atomic masses, that is, in atomic mass units. The atomic mass unit, amu, is exactly 1/16 of the mass of a neutral atom of the most abundant isotope of oxygen, O^{16}, 1 amu = 1.657×10^{-24} gm = 931 MEV = 0.999728 awu (atomic weight unit).

ATOMIC NUMBER

An integer Z that expresses the positive charge of the nucleus in multiples of the electronic charge e. It is the number of protons in the nucleus, and is also equal to the number of electrons outside the nucleus of the neutral atom.

ATOMIC WEIGHT

The weight of any atom as measured on an arbitrary scale based on the weight of an oxygen atom. On this scale, the figure 16 is chosen as the weight of an oxygen atom. Adopting this convention, it is found that the weights of atoms of the other elements can be expressed very nearly as whole numbers, called the mass numbers. There are two scales in use for atomic weights: the physicists' scale is one in which the abundant form of isotopic oxygen is arbitrarily taken as exactly 16; the chemists' scale takes the average weight of three kinds of oxygen atoms (O^{16}, O^{17}, O^{18}) as they occur in nature as exactly 16. Atomic weights in the chemists' scale are expressed in atomic weight units, awu, where 1 awu = 1/16 (atomic weight of naturally occurring oxygen). The physicists' atomic weights are expressed in atomic mass units, amu, where 1 amu = 1/16 of the atomic weight of the lightest naturally occurring isotope of oxygen. In amu, the atomic weight of natural oxygen comes out 16.00435 amu, and 1 awu = 1.660×10^{-24} gm = 1.000272 amu.

ATTENUATION

A general term used to denote a decrease in magnitude in transmission from one point to another. It may be expressed as a ratio, or, by extension of the term, in decibels. The reduction of intensity of radiation due to scattering and absorption processes while traversing an interposed medium. This is known as particle attenuation or energy attenuation. In radiation theory, the reduction in flux density, or power per unit area, with distance from the source; it may be due to absorption, to scattering, or to a combination of both processes.

In nuclear physics, the reduction of the intensity of radiation upon passage through matter; in general, due to a combination of scattering and absorption. The term is best used in a sense that excludes the geometric decrease of intensity with distance from the source (inverse-square law); the attenuation then depends only on the nature of the radiation and the material traversed.

AUTORADIOGRAPH

Record of radiation from radioactive materials in an object made by placing the object in close proximity to a photographic emulsion.

BACKGROUND RADIATION

Ionizing radiation arising from within the body and from the surroundings to which individuals are always exposed. The main sources of natural background radiation are:

Potassium 40 (K^{40}) in the body
Potassium 40
Thorium (Th)
Uranium (U)
And their decay products (including radium (Ra), and radon (R) in rocks)
Cosmic rays

An estimated dose per year from these sources for sea level and 5000 feet altitude follows.

Source	Rads per year	
	Sea level	5000 feet
1. K^{40} in body	0.020	0.020
2. Th, U, Ra, K^{40}, in granite	0.090	0.090
3. Cosmic rays	0.035	0.050
TOTALS	0.145	0.160

Normally, additional radiation dose is obtained from radioactive watch and instrument dials, medical X-rays, etc.

BETA DECAY

Radioactive transformation of a nuclide in which the atomic number changes by ±1, but the mass number remains unchanged. Increase of atomic number occurs with negative beta particle emission, decrease with positive beta particle (positron) emission, or upon electron capture. Synonym: beta disintegration.

BETA PARTICLE

A negative electron or a positive electron (positron) emitted from a nucleus during beta decay. The β, β^-, and β^+, symbols are reserved for electrons of nuclear origin.

While beta particles are emitted by the nucleus, it is not thought that electrons are contained in the nucleus as such. It is believed, however, that they are created (and immediately emitted) by a transformation of some of the energy in the nucleus.

BETA RAY

A synonym for beta particles. A radiation more penetrating but less ionizing than alpha rays. The rays are deflected by electric and magnetic fields and consist of high-speed electrons.

BREMSSTRAHLEN

The radiation produced in the bremsstrahlung process.

BREMSSTRAHLUNG

A term adopted from German, meaning "braking radiation". The production of electromagnetic radiation by the acceleration (either positive or negative) that a fast, charged particle (usually an electron) undergoes from the effect of an electric or magnetic field; for instance, from the field of another charged particle (usually a nucleus). The spectral distribution is continuous, the well-known continuous X-radiation being a prominent example. For very energetic electrons (above about 50 Mev), the energy loss by radiation far exceeds that by ionization as a stopping mechanism in matter; this process is sometimes called outer bremsstrahlung. A very weak electromagnetic radiation with a continuous spectral distribution is sometimes observed from active substances; this is due to bremsstrahlung of the outer or inner types, or a combination of both.

Sometimes the radiation resulting from the bremsstrahlung process, although here the proper term is bremsstrahlen.

BREMSSTRAHLUNG, INNER

A process occurring infrequently in beta disintegration and resulting in the emission of a photon of energy between zero and the maximum energy available in transition.

BYPRODUCT MATERIAL

Radioactive material, except special nuclear material. Derived from the process of producing or using special nuclear material; or made radioactive by exposure to the radiation incident to the process of producing or using special nuclear material.

CALIBRATE

To ascertain, usually by comparison with a standard, the locations at which scale graduations should be placed to correspond to a series of values of the quantity which an instrument is to measure.

CALIBRATE, TELEMETERING

Determination of the factor existing between the input measure and the output signal of a telemetering pickup or other measuring device.

CHROMOSOME

One of the bodies of the cell nucleus made up of chromatids and usually constant in number in the cells of any one kind of plant or animal.

CONTAMINATION, RADIATION

A condition in which an undesirable radioactive substance is mixed with a desired substance. A condition in which radioactive material has spread to places where it may harm persons, spoil experiments, or make products or equipment unsuitable or unsafe for specific use. In nucleonics "contamination" usually means radioactive contamination.

CORPUSCULAR EMISSION

The full complement of secondary charged particles (usually limited to electrons) associated with an X-ray or gamma-ray beam in its passage through air. The full complement of electrons is obtained after the radiation has traversed sufficient air to bring about equilibrium between the primary photons and secondary electrons. Electronic equilibrium with the secondary photons is intentionally excluded.

COSMIC RAYS

Radiation that has its ultimate origin outside the earth's atmosphere, that is capable of producing ionizing events in passing through air or other matter, and that includes constituents capable of penetrating many feet of material such as rock. The primary cosmic rays probably consist of atomic nuclei, mainly protons, some of which may have energies of the order of 10^{10} to 10^{17} electron volts. Secondary cosmic rays are produced when the primary rays interact with nuclei and electrons, for example in the earth's atmosphere; they consist mainly of mesons, protons, neutrons, electrons, and photons that have less energy than the primary rays. Practically all of the primary cosmic rays are absorbed in the upper atmosphere. Almost all cosmic radiation observed at the earth's surface is of the secondary type.

COSMIC RAYS, HARD COMPONENT

That portion of cosmic radiation that penetrates a moderate thickness of an absorber (usually 10 cm of lead). The hard component, except near the top of the atmosphere, consists of mesons to a predominant degree, but includes some fast protons and fast electrons.

COSMIC-RAY SHOWER

The simultaneous appearance of several of many light ionizing particles with or without accompanying photons, the particles being directed predominantly downward and having a common ultimate origin in an event caused by a single cosmic ray. Showers reveal themselves by the simultaneous activation of separated counters and (sometimes spectacularly) in cloud chambers. They can be roughly classified according to their properties as narrow showers, extensive (auger) showers, penetrating showers, and cascade showers.

COSMIC-RAY SHOWER, PENETRATING

A cosmic-ray shower in which some or all of the constituent particles are capable of greater penetration of absorbing material than is possible for electromagnetic radiation; therefore it is not a cascade shower. In practice the term usually refers to a shower that contains particles capable of penetrating more than 15 or 20 cm of lead. The particles are often pi mesons.

COSMIC-RAY, SOFT COMPONENT

That portion of cosmic radiation that is absorbed in a moderate thickness of an absorber (usually 10 cm of lead). It consists mainly of electrons, positrons and photons, but contains some slow mesons, protons, and other heavy particles often present in cosmic radiation.

COUNT

In radiation measurement, the external indication of a device designed to count ionizing events. It may refer to a single detected event, or to the total registered in a given period of time. The term is loosely used to designate a disintegration, ionizing event, or voltage pulse.

CURIE

The unit of radioactivity defined as the quantity of radioactive nuclide in which the number of atomic disintegrations per second is 3.7×10^{10}.

CUSTODIAN

A person approved by the radiological and isotopes committee qualified to receive, use, and have custody of radiation sources.

DECAY

The disintegration of the nucleus of an unstable nuclide by the spontaneous emission of charged particles and/or photons.

DECONTAMINATE

To remove chemical, biological, or radioactive contamination from, or neutralize it on a person, object, or area. Decontamination may be accomplished by washing, or in case of gases by filtering and washing with water or chemicals.

DECONTAMINATION FACTOR

In nuclear engineering, the ratio between the amount of undesired radioactive material initially present and the amount remaining after a suitable processing step has been completed. Decontamination factors may refer to the removal of some particular type of radiation or of a gross measurable radioactivity.

DETECTION

A process by which the pressure, and sometimes, qualitatively, the amount of radiation or neutron flux may be determined. In this sense, not equivalent to measurement.

DETECTOR

A device to effect the process of detection. A device which performs the function of identification and/or location.

DETECTOR, FISSION CHAMBER

A slow-neutron detector, consisting of an ionizing chamber operated in the proportional region. Its walls are lined with a thin layer of purified U^{235} or Pu^{239}. Slow and thermal neutrons are captured in the uranium or plutonium, and the resulting fissions cause very large ionization pulses in the instrument.

DETECTOR, GEIGER COUNTER

Historically, a "point counter". By popular usage, a Geiger-Muller counter tube or such together with its associated electronic equipment.

DETECTOR, INFRARED

Thermal devices for observing and measuring infrared radiation; e.g., the bolometer, radiomicrometer, thermopile, pneumatic cell, photocell, photographic plate, and photoconductive cell.

DETECTOR, IONIZATION CHAMBER

A device which detects ionizing radiations by means of the ionization produced in a volume of gas. The ions so produced are collected (swept out) by a potential difference applied across the gas volume by a pair of electrodes.

DETECTOR, NEUTRON FISSION-SCINTILLATION

A slow neutron detector. A material capable of producing luminescence when bombarded by fission fragments that is mixed with an enriched uranium compound. A scintillation counter detects the luminous flashes in a flux of slow or thermal neutrons.

DETECTOR, PROPORTIONAL COUNTER

A type of gas-filled radiation counter in which the magnitude of the pulse generated per count is proportional to the energy of the particle or photon being counted. It is thus able to distinguish alpha particles and protons from beta rays and gamma rays. A specific type of proportional counter for fast neutrons which contains hydrogen (or a hydrogeneous gas, such as methane) or has walls which contain material having hydrogen in it. Fast neutrons react with the hydrogen, ejecting recoil protons upon collision. The recoiling protons produce large pulses of ionization similar to those from an alpha particle. In the proportional region of the tube characteristic ionization resulting from beta or gamma radiation can be easily discriminated from that produced by the protons.

DETECTOR, SCINTILLATION COUNTER

The combination of phosphor, photomultiplier tube, and associated circuits for counting scintillation. Incident ionizing radiation striking a phosphor crystal generates photons which, in turn, strike the photocathode of a photomultiplier tube. The electrons generated in this way are drawn by an electric field to the first plate of the tube, where secondary electrons are ejected, the multiplication being five or more for each primary electron. These electrons in turn strike the second plate of the tube where the same thing occurs. A typical tube may have ten or more such plates or stages (dynodes) giving very high amplifications. The current output of the tube is fed to a vacuum-tube amplifier and then to a counter where the pulses may be recorded, or to an instrument where the integrated current of the pulses gives an indication of the number of pulses being received per second.

DOSAGE

A term erroneously used to mean dose. Actually, dosage is a schedule for administering radiation doses as set up, for instance, by a radiologist, giving the doses and the times they are to be administered. Also, it is a prescribed quantity of radiation, i.e., the amount of the dose prescribed for delivery to a patient.

DOSE

The preferred term is absorbed dose. Absorbed dose of radiation has been defined by the International Committee on Radiological Units as "the amount of energy imparted to matter by ionizing particles, per unit mass of irradiated material, at the place of interest". It is expressed in radiation absorbed dose or rads. One rad is defined as 100 ergs/gm. Thus the rad unit is applicable to any type of ionizing radiation, but in reporting dose, (1) the type must be specified, as well as (2) the irradiated material (for instance, tissue) and (3) the place of interest. Without the above three factors, a statement of absorbed dose received is incomplete and probably useless, since the same dose of different kinds of radiation even delivered to the same place can produce entirely different effects.

DOSE RATE

The absorbed dose received (1) in a given medium, (2) at a specified place (3) from a described type of radiation, per unit time. Units: rads/hour. Roentgens/hour which is a measure of ionization in free air is still often used for gamma and X-rays.

DOSE, WHOLE-BODY

The absorbed dose received by a body when energy of radiation and exposure conditions are such that it can be assumed that the entire body received approximately the same dose.

DOSIMETER

Any instrument which measures radiation dose.

ELECTRON

One of the smallest known particles having an electric charge. That part of an atom outside the nucleus is composed of electrons, the number of which, being equal to the protons in the nucleus, is the same as the atomic number of the atom. An electric current is a conductor consisting of the motion of electrons through the material of the conductor. A current of one ampere corresponds to the passage of 6.24×10^{18} electrons in one second. In radio tubes and cathode ray tubes, the current is carried by a stream of electrons. The beta particles emitted by certain radioactive materials are high speed electrons.

The mass of all the electrons contained in a lump of matter is only about 1/3600 of the total mass, most of the mass being contained in the atomic nuclei. An electron in rapid motion has more mass than one at rest because of the mass-equivalence of its energy of motion. An electron accelerated through 512 kv has twice as much mass as one at rest. Thus, the beta particles as they are emitted by radioactive materials, and the electron in high voltage X-ray tubes, may have several times their normal mass. The rest mass of the electron, m_0, is equal to 9.107×10^{-28}g, and its charge, e, is equal to 4.802×10^{-10} statcoulomb or 1.6×10^{-19} coulomb. Its charge may be either positive or negative. The positive electron is almost always called a positron; the negative electron is rarely called the negatron. Almost always the term electron means negatron. The negative electron is a constituent of all atoms. In a neutral atom the number of electrons is equal to the atomic number Z.

The electron has an intrinsic magnetic moment:

$$u = u_0 \left(1 + \frac{c^2}{hc}\right)$$

Where u_0 is the Bohr magnetron, h is Plancks constant, and c is the velocity of light. It has a spin-quantum number of 1/2 and is described by the Fermi-Divac statistics.

ELECTRON UNIT

A unit of electric charge (negative or positive) equal to the charge on an electron.

ELECTRON VOLT

A unit of energy equal to 1.60203×10^{-12} erg. It is the energy gained by an electron in passing through a potential difference of one volt. In this definition, any bremsstrahlung which may be emitted from the system due to acceleration of the electron is neglected. The symbol ev is used for an electron volt. One Mev = 10^6 ev.

FALLOUT

That part of the material carried into the air by a surface or subsurface nuclear explosion which descends to the earth or water either locally or beyond the sight of the explosion.

Detectable amounts of fallout may appear over distances of hundreds or thousands of miles for months after an explosion.

Fallout particles (inland detonations) and droplets (in water detonations) contain radioactive nuclei caused by neutron bombardment of the medium surrounding the bomb. Air bursts generally do not result in as much fallout as does a ground-level burst. The degree of fallout, however, depends on the materials in the explosion.

FILM BADGE

A dosimeter consisting of an appropriately packaged photographic film for detecting radiation exposure of personnel; it is usually dental-size X-ray film, worn on the person and frequently combined with an identification badge. The badge may contain two or three films of different sensitivity, and it may contain a filter that shields part of the film from beta radiation.

HALF-LIFE EFFECTIVE

Time required for a radioactive element fixed in the tissue of an animal body to be diminished 50 percent as a result of the combined action of radioactive decay and biological elimination.

HALF-LIFE, RADIOACTIVE

Time required for a radioactive substance to loose 50 percent of its activity by decay. Each radionuclide has a unique half-life.

HALF-VALUE LAYER (HALF-THICKNESS)

The thickness of any particular material necessary to reduce the intensity of an X-ray or gamma-ray beam to one-half of its original value.

HEALTH PHYSICS

A term in common use for that branch of radiological science dealing with the protection of personnel from harmful effects of ionizing radiation.

HIGH-RADIATION AREA

Means an area, accessible to personnel, in which there exists radiation originating in whole or in part within licensed material at such levels that a major portion of the body could receive in any one hour a dose in excess of 100 millirads.

INTERLOCK

A device, usually electrical and/or mechanical, to prevent activation of a control until a preliminary condition has been met or to prevent hazardous operation. Its purpose usually is safety of personnel or equipment. For example, an interlock may be provided to prevent withdrawing control rods to start a reactor until flow of coolant has been established.

INTERNAL RADIATION

Exposure to ionizing radiation when the radiation source is within the body as a result of deposition of radioelements in body tissue.

INVERSE-SQUARE LAW

The intensity of radiation at any distance from a point source varies inversely as the square of that distance; e.g., if the radiation exposure is 100 r/hr at one inch from a source, the exposure will be 0.01 r/hr at 100 inches.

ION

An atom, atomic particle, or chemical radical bearing a positive or negative charge, sometimes a free electron or other charged subatomic particle. An ion pair consists of a positive ion and a negative ion (usually an electron), having charges of the same magnitude and formed from a neutral atom or molecule by the action of radiation. A primary ion pair is produced directly by the causative radiation. An ion cluster is a group of ion pairs, primarily ion pair and any secondary ion pairs, formed as by a beta ray.

Note: Acids, bases, and salts (electrolytes) when dissolved in certain solvents are more or less disassociated into electrically charged units, or parts of the molecules, i.e., ions. Some electrolytes disassociate into ions when fused. Positive ions are atoms or group of atoms which have lost valence electrons; negative ions are those to which electrons have been added.

IONIZATION

Any process by which a neutral atom or molecule loses or gains electrons, thereby acquiring a net charge; the process of producing ions.

IONIZATION GAGE

A high vacuum gage in which the amount of ionization present gives a measure of gas pressure within the gage. It consists of a triode, mounted in a glass bulb having an opening connected to the vessel in which the pressure is to be measured. The plate is biased positively and the grid negatively. Electrons from the hot cathode ionize the gas molecules in the tube, and the plate current is a measure of the ions present. For pressures below 10^{-4} mm/Hg. the ion current is proportional to the pressure, and the gage may be used down to pressures of about 10^{-10} mm/Hg.

IONIZATION POTENTIAL, CRITICAL

A measure of the quantity of energy per unit charge (expressed in volts) required to remove an electron from the lowest energy of a neutral atom, to a sufficient distance that the atom remains positively ionized.

IONIZATION, PRIMARY

In collision theory, the ionization produced by the primary particles as contrasted to total ionization which includes the secondary ionization produced by beta rays.

In counter tubes, the total ionization produced by incident radiation without gas amplification.

IONIZATION, TOTAL

The total electric charge on the ions of one sign when the energetic particle that has produced these ions has lost all of its kinetic energy. For a given gas, the total ionization

FILM RING

A film-badge dosimeter in the form of a finger ring.

GAMMA RAY

A nonmaterial shortwave radiation emitted by radioactive atoms. It is of the same nature as the X-rays produced by a high-voltage X-ray tube. Gamma radiation, X-radiation, and ordinary light consist of electromagnetic waves. Gamma radiation differs only in that it comes from the nucleus of the atom rather than from the electrons outside the nucleus which are the source of X-rays and visible light.

The National Research Council has defined a gamma ray as a quantum (photon) of electromagnetic radiation emitted by a nucleus, each such photon being emitted as the result of a quantum transition between two energy levels of the nucleus. Gamma rays have energies usually between 10 Kev and 10 Mev, with correspondingly short wavelengths and high frequencies. They are often associated with alpha and beta radioactivity, following transitions that leave the product nuclei in excited states. They also occur in isometric transitions and in many induced nuclear reactions. A gamma-ray spectrum consists of one or more sharp lines, each corresponding to an energy and intensity that are characteristic of the source.

Sometimes they are loosely defined as X-ray photons of high energy, exceeding about 1 Mev, or an annihilation-radiation photon, each of which differs from a gamma ray in sense only in its mode of origin.

Gamma rays are produced in considerable quantity by the fission process, to the extent of about 6 Mev of gamma energy per fission. The symbol for a gamma photon is usually written as hv, where h is Planck's 6.624×10^{-27} erg-sec, and v is the frequency of the electromagnetic radiation in sec-1. So expressed, the symbol represents the energy of the photon in ergs. Gamma rays are extremely penetrating, and often a hazard to health or life in nuclear-reactor work and radioisotope work. They cause ionization in the body and in all other materials through several processes, the most notable of which are the photoelectric effect and pair production.

Gamma rays move with the velocity of light c, equal to 3×10^{10} cm/sec, as do all electromagnetic waves. According to the principles of relativity, there is a momentum associated with a gamma photon p=hv/c.

GENE

An element of the germ plasm that transmits hereditary characters. It is considered a complex self-perpetuating protein molecule, and occurs in the chromosomes.

HALF-LIFE BIOLOGICAL

Time required for the body to eliminate one-half of an administered dose of any substance by regular processes of elimination. This time is approximately the same for both stable and radioactive isotopes of a particular element.

is closely proportioned to the initial energy and is nearly independent of the nature of the ionizing particle. It is frequently used as a measure of particle energy.

The total number of ion pairs produced by the ionizing particle along its entire path.

IONIZATION, VOLUME

Average ionization density in a given volume irrespective of the specific ionization of the ionizing particles.

IONIZING ENERGY

Symbol W. The average energy lost by an ionizing particle in production of an ion pair in a gas. It is slightly different for each type of particle, each particle energy, and each gas; although for air, electrons, protons, and alpha particles possess values lying between 32 ev and 35.6 ev. The accepted value as of 1957 is 34 ev for medium-energy electrons in air. Synonym: energy lost per ion pair. Thus, since all the kinetic energy of a gamma photon is ultimately lost through ionization (if the medium is large enough), the number of ion pairs produced will be approximately the photon energy in ev divided by 34.

IONIZING PARTICLE

A particle that directly produces ion pairs in its passage through a substance. In practice, it is a charged particle having considerably greater kinetic energy than the ionizing energy appropriate to the medium.

Thus, the term does not refer to neutrons or gamma photons, although, of course, in the latter case some primary ionization occurs.

IONIZING RADIATION

See radiation, ionizing.

ISOTOPE

One of several nuclides having the same number of protons in their nuclide, and hence belonging to the same chemical species, but differing in the number of neutrons, and therefore in mass number A. For example, ${}_6C_6{}^{12}$, ${}_6C_7{}^{13}$, ${}_6C_8{}^{14}$ are isotopes of carbon. Small quantitative differences in chemical properties exist between isotopes.

A synonym for isotopic tracer.

A radionuclide or a preparation of an element with special isotopic composition (allobar) as an article of commerce, so called because of the principal use of such materials or isotopic tracers.

Through shortening of the expression radioactive isotope, the term isotope has popularly become synonymous with nuclear species, for instance, an isotope laboratory, isotope catalog.

LABELED COMPOUND

A compound consisting, in part, of labeled molecules. By observations of radioactivity or isotopes composition, this compound or its fragments may be followed through physical, chemical, or biological processes.

LEAKAGE (OR DIRECT) RADIATION

The radiation which escapes through the protective shielding of an X-ray tube or teletherapy unit. Diagnostic X-ray tubes should have sufficient shielding to reduce the leakage radiation to 0.1 r per hour at one meter from the target of the tube under maximum rated X-ray tube potential and current. The shielding incorporated in therapeutic X-ray tubes should limit the leakage radiation to a maximum of 1.0 r per hour at one meter from the target of the tube under the maximum conditions.

LICENSE

Means a license issued under regulations in part 30, 40, or 70 of Title 10, Code of Federal Regulations. Licensee means the holder of such license.

LICENSED MATERIAL

Source material, special nuclear material, or byproduct material received, possessed, used, or transferred under a general or special license issued by the AEC pursuant to the Code of Federal Regulations, Title 10, Chapter 1.

NEUTRAL ATOM

An atom in which the sums of the positive charges are equal, resulting in zero effective charge. An un-ionized atom.

NEUTRON

A particle with no electric charge, but with a mass approximately the same as that of the proton. In nature, neutrons are locked in the nucleus of an atom, but they can be knocked out in various kinds of atom-smashing experiments. The number of neutrons (N) in a particular nucleus is found by subtracting the atomic number (Z) from the atomic weight (mass number A). Neutrons were discovered by Chadwick who obtained them by bombarding beryllium atoms with alpha particles from radium. This procedure knocked the neutrons out of the beryllium nuclei. The process is still a useful laboratory way of producing streams of free neutrons of low intensity.

Neutrons play an especially important role in the practical utilization of atomic energy, because when a uranium atom undergoes fission through the capture of a neutron, several more neutrons are produced which continue the process by the mechanism of chain reaction.

Because they are electrically neutral, neutrons can move rather freely through most solid materials. They are, however, scattered by impact with the nuclei so that they move through matter by diffusion rather than by direct forward motion. Likewise, they are absorbed to some extent, the free neutrons being captured by nuclei to form new isotopes which are in some cases radioactive.

The ability of nuclei thus to capture neutrons varies enormously from one atomic species to another, and depends very greatly on the speed of the neutrons. Some substances are almost transparent to neutrons, others almost opaque. There is no known substance which will act like a wall for neutrons and bounce back all the neutrons that strike it, in a way that a steel boiler wall bounces back the molecules of steam that strike it.

A neutron is an elementary particle of mass number 1. It is a constituent of all nuclei of mass number greater than 1. It is unstable with respect to beta decay, disintegrating to give $_1H^1$ plus a beta particle with a half-life of about 13 minutes. It produces no detectable primary ionization in its passage through matter, but interacts with matter predominately by collisions (recoil nuclei, gamma rays from inelastic scattering and from neutron capture) and, to a lesser extent, magnetically. Some properties of the neutron are: rest mass, 1.00982 amu and charge, 0 esu.

NEUTRON-BINDING ENERGY

The energy required to remove a single neutron from a nucleus. The neutron-binding energy for a nuclide Z^A is equal to the energy released when a neutron is added to the nuclide Z^{A-1}. Most known neutron-binding energies are in the range 5 to 12 Mev, although that for H^2 is 2.23 Mev; that for Be^9 is 1.67 Mev; that for He^4 is 20.58 Mev; and that for He^5 is negative by about 0.8 Mev. The magnitude of the binding energy per nucleon is a measure of stability of the nucleus against beta decay (but not against alpha decay). The average value for heavier isotopes is about 8 Mev.

NUCLEAR EMULSION

An emulsion similar to a photographic emulsion, but designed to register the track of a charged particle as a series of dark grains. Microscopic examination is necessary. The emulsion is usually prepared in the form of a layer (often supported on a glass sheet) called a nuclear plate. A variety of nuclear emulsions is available for different kinds and energies of particles. Such graphic emulsions, some as thick as one millimeter, usually have a much higher content of silver halide, most often a fine-grain silver bromide. Nuclear emulsions are used in dosimetry where the number of neutrons (proton-recoil) tracks in the emulsion is related to the neutron dose (called NTA film, neutron track A) and in neutron-spectroscopy work.

NUCLEAR ENERGY

Energy held within the nucleus of an atom, released in part in certain isotopes through radioactivity, or by the process of fission, or in certain other elements by procession of nuclear fusion (sometimes, that part of this energy which is released by fission or fusion).

In nuclear fission the energy released comes from splitting the atomic nucleus, resulting in the emission of nuclear particles such as neutrons, alpha particles, and beta particles.

In nuclear fusion, the combining atomic nuclei fail to utilize their atomic mass in forming the new nucleus, the unused mass being connected into energy according to the formula $E=MC^2$, where E is energy, M the mass, and C the velocity of light (299,796 kilometers/second); e.g., H^2 (2.014741) + H^2 (2.014741) = He^4 (4.003873) + 0.025609 amu, the latter amount of atomic mass being the measure of released energy, about 0.7% of the original atomic mass. Thus nuclear energy may be used as a synonym for "atomic energy", or occasionally for nuclear-disintegration energy, but not usually for nuclear-binding energy.

NUCLEAR-ENERGY LEVEL

One of the quantum series of energy levels which can be assumed by a given nucleus. If the level is the lowest of the series, the nucleus is said to be in its ground state. If it is not the lowest, the nucleus is excited. If it remains in an excited state for an appreciable length of time, it is in a metastable state. Nuclei go from excited states to the ground state through gamma emission, internal conversion, or internal pair formation.

NEUTRON FLUX

A term used to express the intensity of neutron radiation; the number of neutrons passing through a unit area in unit time. For neutrons of a given energy, the neutron flux is the product of the neutron density and average speed. In the physical sense, the term neutron flux (or simply flux) is the neutron-flux density. It is expressed in neutrons/CM^2-sec; the common symbol is nv, where n is neutron density in CM^{-3}, and v is the average neutron speed in cm-sec^{-1}.

NEUTRON NUMBER

The number N of neutrons in a nucleus. It is equal to A-Z, the difference between the mass number and the atomic number. When it is desired to indicate explicitly the neutron number in the symbol of a nuclide, the number is added as a subscript following the element symbol, thus, in ${}_{26}Fe^{59}_{33}$, N is 33.

NEUTRON RADIATIVE CAPTURE

The capture of a neutron (usually a slow neutron) by an atomic nucleus. Capture is usually followed immediately by the emission of gamma radiation from the nucleus. The energy of this radiation is equal to the binding energy of the neutron in the nucleus.

NEUTRON REST MASS

The neutron rest mass is $M_M = 1.67474 \times 10^{-24}$ gm.

NEUTRON SOURCE

Any material that emits neutrons; e.g., a mixture of radium and beryllium. A neutron source may be introduced into a nuclear reactor as the start-up procedure. The use of a neutron source is a safety measure to ensure having at the start a neutron flux large enough to be distinguished from background and measured quickly. Otherwise, as control rods were withdrawn, the reactor might reach a critical condition before its flux has risen high enough for the control system to operate. Especially if the reactor has become prompt-critical, a rapid and uncontrolled increase in power to harmful level might then result. When such a source is used, the control instruments show at an earlier stage the approach to critical conditions as safety and control rods are withdrawn. Also used in critical experiments.

NUCLEAR-BINDING ENERGY

The energy that would be required to separate a nucleus of atomic number Z and mass number A into Z protons and N=A-Z neutrons. It is the energy equivalent of the difference between the sum of the masses of the product particles (hydrogen atoms and neutrons) and the mass of the atom. The nuclear-binding energy is the energy equivalent to the mass defect. It is given in Mev by the expression $B=ZM_p + NM_n - M$, where Z (the atomic number) is the number of protons in the nucleus and the number of orbital electrons; N is the number of neutrons in the nucleus; M_p and M_n are the masses of the proton and neutron respectively; and M is the accurately expressed mass of the nucleus.

NUCLEAR FISSION

The splitting of an atomic nucleus, as by neutron bombardment. In an atomic bomb, nuclear fission is carried out so as to release great amounts of energy manifested by thermal radiation, nuclear radiation, and blast.

NUCLEUS

The central part of the atom, which makes up most of the weight of the atom and is charged with positive electricity. Atomic nuclei are composed of two kinds of fundamental particles; neutrons and protons. The total number of particles of both kinds in the nucleus is given by the atomic weight (or mass number, A). The number of protons is given by the atomic number (Z). Thus the charge on the nucleus is +Ze, where e is the electronic charge. The number of neutrons can thus be found by subtracting the atomic number from the atomic weight. In uranium 238, for example, the total number of protons and neutrons is 238. The number of protons alone, given by the atomic number of uranium is 92. Hence, by subtraction, the number of neutrons is 238-92=146.

In the atoms of certain elements, the nuclei, while all having the same number of protons (i.e., the same atomic number), differ as to atomic weight (see Isotope). For example, most hydrogen atoms have a single proton for a nucleus. Consequently, hydrogen is said to have an atomic weight of one. But there are hydrogen atoms with a nucleus compounded of one proton and one neutron. These heavier atoms can be separated from the lighter, more normal, hydrogen atoms to make heavy hydrogen (deuterium), a material with the same chemical properties as hydrogen, but with a mass number of two. Some elements are represented by atoms of many different weights. An atom of mercury for example may have any one of seven different atomic weights, 196, 198, 199, 200, 201, 202, or 204.

NUCLIDE

A species of atom characterized by the constitution of its nucleus. The nuclear constitution is specified by the number of protons Z, the number of neutrons N, and energy content; or, alternately, by the atomic number Z, mass number A = (N + Z), and atomic mass. To be regarded as a distinct nuclide, the atom must be capable of existing for a measurable time (generally not greater than 10^{-10} sec). Thus nuclear isomers are considered different nuclides, whereas promptly decaying excited nuclear states and unstable intermediates in nuclear reactions are not so considered.

PERSON

Any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, government agency other than the Commission, any state, any foreign government or nation or any political subdivision of any such government or nations, or other entity; and any legal successor, representative, agent, or agency of the foregoing (as defined by the Atomic Energy Commission).

PERSONNEL-MONITORING EQUIPMENT

Such devices designed to be worn or carried by an individual to measure the dose received (film badges, pocket chambers, pocket dosimeters, film rings, etc.).

PROTECTIVE BARRIERS

Barriers of radiation absorbing material such as lead, concrete, and plaster used to reduce radiation hazards.

PROTON

A positively charged elementary particle of mass number 1 and charge equal in magnitude to the electronic charge e. The proton mass is approximately 1836 times as great as the electron mass. It is one of the constituents of every nucleus; the number of protons in the nucleus of each atom of the element is given by the atomic number Z of the element. Other properties of the proton are: rest mass, 1.67×10^{-24} gram, or 1.00759 amu. The nucleus of an atom of hydrogen of mass number 1 is a proton. The term nucleon applies either to a neutron or a proton; i.e., to either of these two component particles of nuclei. See Nucleus.

PROTON-BINDING ENERGY

The energy required to remove a single proton from a nucleus. The proton-binding energy for a nuclide Z^A is equal to the energy released when a proton is added to the nuclide $(Z-1)^{A-1}$. Most known proton-binding energies are in the range 5 to 12 Mev, although that for H^2 is 2.23 Mev, that for He^4 is 19.81 Mev, and those for Li^5 and B^9 are negative.

PROTON-TO-ELECTRON MASS RATIO

The ratio of the proton mass, H^+, to the electron rest mass, M_e. Thus $H^+/M_e = 1836.13 + 0.04$.

RAD

The unit of radiation absorbed dose, which is 100 ergs/gram. The RAD is a measure of the energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest.

RADIANT INTENSITY

Symbol J. Of a source, the energy emitted per unit time, per unit solid angle about the direction considered; e.g., watts/steradian. Thus: $J = 4\ \phi/dw$ where ϕ = radiant flux and dw is the incremental solid angle.

RADIATING ATOM

An atom which is the source of electromagnetic radiations. These radiations are the product of electron transfer from one energy level to a lower energy level.

RADIATION

Any or all of the following: alpha rays, beta rays, gamma rays, X-rays, neutrons, high-speed protons, and other atomic particles; not sound or radio waves, or visible, infrared, or ultraviolet light.

RADIATION ANNIHILATION

Electromagnetic radiation produced by the union and consequent annihilation of a positron and an electron, or between any two particles. Each such annihilation usually produces two (rarely one or three) photons. These photons have properties identical with those of gamma rays, and accompany the decay of all positron-emitting radioactive substances. A positron and an electron are most likely to unite when their relative velocity is small; hence the energy available for annihilation radiation will be that of the rest masses of the electron $2m_eC^2$ (=1.02 Mev) and the process will usually result in the production of two oppositely directed photons, each of energy 0.15 Mev.

RADIATION AREA

Any area accessible to personnel, in which radiation, originating in whole or in part within licensed material, exists at such levels that a major portion of the body could receive in any one hour a dose in excess of 2 millirems, or in any 7 consecutive days a dose in excess of 100 millirems.

RADIATION DAMAGE

A general term for the effects of radiation (gamma rays, fission fragments, and neutrons) upon substances. Dissociation of compounds may occur. Gases may be evolved. Changes in solids are related also to disruption of crystal structures, and include changes in mechanical properties and dimensions, thermal conductivity, electrical conductivity, etc.

RADIATION INTENSITY

The radiation intensity in a given direction is the power radiated from an antenna per unit solid angle in that direction.

The energy per unti time passing through a unit area perpendicular to the direction of propogation. The radiant flux density.

NOTE: In dealing with X-rays and radioactivity, the term radiation intensity is often erroneously used as a synonym for dose rate.

RADIATION, IONIZING

An electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

RADIATION, NUCLEAR

Radiation which is emitted by the nucleus. This includes gamma rays, beta and alpha particles, and sometimes neutrons or protons. It does not include X-rays.

RADIATION-PRODUCING EQUIPMENT

Any device, machine, or equipment capable of producing radiation (X-ray tubes, accelerators, cathode ray tubes, klystrons, thyratrons, magnetrons, resonance transformers, electrostatic precipitators, etc.).

RADIATION SICKNESS

In radiation therapy: a self-syndrome (a group of symptoms), characterized by nausea, vomiting, diarrhea, and physic depression, following exposure to appreciable doses of ionizing radiation, particularly to the abdominal region. Its mechanism is unknown and there is no satisfactory remedy. It usually occurs a few hours after a severe overdose of nuclear or X-radiation.

RADIATION SOURCE

Any radioactive material or radiation-producing equipment.

RADIOACTIVE ISOTOPE

An isotope which decays spontaneously with the emission of radiation at a definite rate measured by the half-life. The radioactivity is characteristic of nuclei or particular isotopes of an element which determine the chemical properties of the element.

RADIOACTIVE MATERIAL

(Radioactive isotope, radioactive nuclide) Any material which decays spontaneously with the emission of radiation at a definite rate measured by the half-life.

RADIOACTIVE TRACER

A small quantity of radioactive isotope, either with carrier or carrier-force, used to follow biological, chemical, or mechanical processes.

RADIOACTIVITY

Spontaneous nuclear disintegration with emission of corpuscular (particulate) or electromagnetic radiations. The principal types of radioactivity are alpha disintegration, beta decay (electron emission, positron emission), and electron capture, and isometric transition. To be considered as radioactive, a process must have a measurable lifetime; between 10^{-10} second and 10^{17} year, according to present experimental techniques. Radiations emitted within a time too short for measurement are called prompt; however, prompt radiations, including gamma rays, characteristic X-rays, conversion and auger electrons, delayed neutrons, and annihilation radiation are often associated with radioactive disintegrations, since their emission may follow the primary radioactive process.

NOTE: The radioactive atomic species occurring in nature include all elements whose atomic number is greater than that of lead. Since 1930, physicists have succeeded in transmuting nearly all of the chemical elements into radioactive forms by artificial bombardment. Many of such materials are also produced as fission products. The radiations emitted by radioactive materials have proved very useful in the study and treatment of cancer and other tumorous diseases, and in general medical diagnosis and therapy.

RADIOLOGICAL SURVEY

Evaluation of the radiation hazards incident to the production, use, or existence of radioactive or other sources of radiation under a specific set of conditions. Such evaluation customarily includes a physical survey of the disposition of materials and equipment; measurements or estimates of the levels of radiation that may be involved; and a sufficient knowledge of processes using or affecting these materials to predict hazards resulting from expected or possible changes in materials or equipment.

RELATIVE BIOLOGICAL EFFECTIVENESS

The ratio of gamma or X-ray dose to the dose that is required to produce the same biological effect by the radiation in question.

REM

Unit of measurement of dose of ionizing radiation to body tissue in terms of its estimated biological effect relative to a dose of one roentgen (r) of X-ray.

REQUESTOR

A custodian who requests approval for the procurement or transfer of a radiation source.

RESTRICTED AREA

Any area, to which access is controlled by the licensee. "Restricted area" shall not include any area used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.

ROENTGEN

The quantity of X or gamma radiation such that the associated corpuscular emission per 0.001293 grams of air produces, in air, ions carrying one electrostatic unit of quantity electricity of either sign.

SEALED SOURCE

Any radioactive material that is encased in a sealed capsule designed to prevent leakage or escape of the radioactive material.

SHIELDING MATERIAL

Any material which is used to absorb radiation and thus effectively reduce the intensity of radiation, and in some cases eliminate it. Lead, concrete, aluminum, and water are examples of commonly used shielding material.

SPECIFIC ACTIVITY ISOTOPE

Total radioactivity of a given isotope per gram of the radioactive isotope.

SOURCE MATERIAL

Any material except special nuclear material, which contains by weight one-twentieth of one percent or more of uranium, thorium or any combination thereof.

SPECIAL NUCLEAR MATERIAL

Plutonium, uranium 233, uranium enriched in the isotope 233, or in the isotope 235, and any other material which the Commission, pursuant to the provisions of section 51 of the act, determines to be special nuclear material, but does not include special source material.

Any material artificially enriched by any of the foregoing, but not including source material.

X-RAY HARDNESS

Hardness is the attribute which determines the penetrating ability of X-rays. The shorter the wavelength, the harder the rays and the greater their penetrating ability. Hardness is measured by the X-ray energy or quality.

X-RAY POTENTIAL, EQUIVALENT CONSTANT

The constant potential which must be applied to an X-ray tube to produce radiation having an absorption curve in a given material closely similar to that of the beam under consideration. Electromagnetic radiation of wavelengths less than about 100 angstrom units, produced: (1) when electrons striking a target loose kinetic energy in passing through the strong electric fields surrounding the target nuclei, thus giving rise to bremsstrahlung and resulting in a continuous X-ray spectrum; (2) by the transitions of electrons from various atomic orbits or energy states to lower energy states, thus giving rise to characteristic X-rays. The term X-rays is not used to refer to the charactistic radiation from an element of atomic number Z less than 10, since the wavelengths of such radiation exceed those in the X-ray range. X-rays are usually discussed in terms of (1) their photon energies (hv, where h is Planck's constant, and v is the frequency) in units of electron volts, or (2) the potential across the X-ray tube. X-rays and gamma rays are identical in all respects, except as to source (gamma rays are emitted only by nuclei). The term Roentgen rays is synonymous, and is used mostly in medicine.

X-RAYS, SECONDARY

The X-rays emitted by any matter irradiated with primary X-rays. Fast-moving electrons are generated by the photoelectric, Compton, or pair production process, and these electrons then generate the secondary X-rays.

APPENDIX B

CONCENTRATIONS OF RADIOACTIVE MATERIALS IN AIR AND WATER ABOVE NATURAL BACKGROUND

(See notes at end of appendix)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week Column 1 Air (μc/ml)	Table I 40 Hour Week Column 2 Water (μc/ml)	Table II 168 Hour Week Column 1 Air (μc/ml)	Table II 168 Hour Week Column 2 Water (μc/ml)
Actinium 89	Ac 227	S	$2X10^{-12}$	$6X10^{-5}$	$8X10^{-14}$	$2X10^{-6}$
		I	$3X10^{-11}$	$9X10^{-3}$	$9X10^{-13}$	$3X10^{-4}$
	Ac 228	S	$8X10^{-8}$	$3X10^{-3}$	$3X10^{-9}$	$9X10^{-5}$
		I	$2X10^{-8}$	$3X10^{-3}$	$6X10^{-10}$	$9X10^{-5}$
Americium 95	Am 241	S	$6X10^{-12}$	$1X10^{-4}$	$2X10^{-13}$	$4X10^{-6}$
		I	$1X10^{-10}$	$8X10^{-4}$	$4X10^{-12}$	$2X10^{-5}$
	Am 243	S	$6X10^{-12}$	$1X10^{-4}$	$2X10^{-13}$	$4X10^{-6}$
		I	$1X10^{-10}$	$8X10^{-4}$	$4X10^{-12}$	$3X10^{-5}$
Antimony 51	Sb 122	S	$2X10^{-7}$	$8X10^{-4}$	$6X10^{-9}$	$3X10^{-5}$
		I	$1X10^{-7}$	$8X10^{-4}$	$5X10^{-9}$	$3X10^{-5}$
	Sb 124	S	$2X10^{-7}$	$7X10^{-4}$	$5X10^{-9}$	$2X10^{-5}$
		I	$2X10^{-8}$	$7X10^{-4}$	$7X10^{-10}$	$2X10^{-5}$
	Sb 125	S	$5X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
		I	$3X10^{-8}$	$3X10^{-3}$	$9X10^{-10}$	$1X10^{-4}$
Argon 18	A 37	Sub[2]	$6X10^{-3}$	-----	$1X10^{-4}$	-----
	A 41	Sub	$2X10^{-6}$	-----	$4X10^{-8}$	-----
Arsenic 33	As 73	S	$2X10^{-6}$	$1X10^{-2}$	$7X10^{-8}$	$5X10^{-4}$
		I	$4X10^{-7}$	$1X10^{-2}$	$1X10^{-8}$	$5X10^{-4}$
	As 74	S	$3X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$5X10^{-5}$
		I	$1X10^{-7}$	$2X10^{-3}$	$4X10^{-9}$	$5X10^{-5}$
	As 76	S	$1X10^{-7}$	$6X10^{-4}$	$4X10^{-9}$	$2X10^{-5}$
		I	$1X10^{-7}$	$6X10^{-4}$	$3X10^{-9}$	$2X10^{-5}$
	As 77	S	$5X10^{-7}$	$2X10^{-3}$	$2X10^{-8}$	$8X10^{-5}$
		I	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$8X10^{-5}$
Astatine 85	At 211	S	$7X10^{-9}$	$5X10^{-5}$	$2X10^{-10}$	$2X10^{-6}$
		I	$3X10^{-8}$	$2X10^{-3}$	$1X10^{-9}$	$7X10^{-5}$
Barium 56	Ba 131	S	$1X10^{-6}$	$5X10^{-3}$	$4X10^{-8}$	$2X10^{-4}$
		I	$4X10^{-7}$	$5X10^{-3}$	$1X10^{-8}$	$2X10^{-4}$
	Ba 140	S	$1X10^{-7}$	$8X10^{-4}$	$4X10^{-9}$	$3X10^{-5}$
		I	$4X10^{-8}$	$7X10^{-4}$	$1X10^{-9}$	$2X10^{-5}$
Berkelium 97	Bk 249	S	$9X10^{-10}$	$2X10^{-2}$	$3X10^{-11}$	$6X10^{-4}$
		I	$1X10^{-7}$	$2X10^{-2}$	$4X10^{-9}$	$6X10^{-4}$
Beryllium 4	Be 7	S	$6X10^{-6}$	$5X10^{-2}$	$2X10^{-7}$	$2X10^{-3}$
		I	$1X10^{-6}$	$5X10^{-2}$	$4X10^{-8}$	$2X10^{-3}$

CONCENTRATIONS OF RADIOACTIVE MATERIALS
IN AIR AND WATER ABOVE NATURAL BACKGROUND
(See notes at end of appendix)
(Cont.)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week Column 1 Air (μc/ml)	Table I 40 Hour Week Column 2 Water (μc/ml)	Table II 168 Hour Week Column 1 Air (μc/ml)	Table II 168 Hour Week Column 2 Water (μc/ml)
Bismuth 83	Bi 206	S	$2X10^{-7}$	$1X10^{-3}$	$6X10^{-9}$	$4X10^{-5}$
		I	$1X10^{-7}$	$1X10^{-3}$	$5X10^{-9}$	$4X10^{-5}$
	Bi 207	S	$2X10^{-7}$	$2X10^{-3}$	$6X10^{-9}$	$6X10^{-5}$
		I	$1X10^{-8}$	$2X10^{-3}$	$5X10^{-10}$	$6X10^{-5}$
	Bi 210	S	$6X10^{-9}$	$1X10^{-3}$	$2X10^{-10}$	$4X10^{-5}$
		I	$6X10^{-9}$	$1X10^{-3}$	$2X10^{-10}$	$4X10^{-5}$
	Bi 212	S	$1X10^{-7}$	$1X10^{-2}$	$3X10^{-9}$	$4X10^{-4}$
		I	$2X10^{-7}$	$1X10^{-2}$	$7X10^{-9}$	$4X10^{-4}$
Bromine 35	Br 82	S	$1X10^{-6}$	$8X10^{-3}$	$4X10^{-8}$	$3X10^{-4}$
		I	$2X10^{-7}$	$1X10^{-3}$	$6X10^{-9}$	$4X10^{-5}$
Cadmium 48......	Cd 109	S	$5X10^{-8}$	$5X10^{-3}$	$2X10^{-9}$	$2X10^{-4}$
		I	$7X10^{-8}$	$5X10^{-3}$	$3X10^{-9}$	$2X10^{-4}$
	Cd 115m	S	$4X10^{-8}$	$7X10^{-4}$	$1X10^{-9}$	$3X10^{-5}$
		I	$4X10^{-8}$	$7X10^{-4}$	$1X10^{-9}$	$3X10^{-5}$
	Cd 115	S	$2X10^{-7}$	$1X10^{-3}$	$8X10^{-9}$	$3X10^{-5}$
		I	$2X10^{-7}$	$1X10^{-3}$	$6X10^{-9}$	$4X10^{-5}$
Calcium 20	Ca 45	S	$3X10^{-8}$	$3X10^{-4}$	$1X10^{-9}$	$9X10^{-6}$
		I	$1X10^{-7}$	$5X10^{-3}$	$4X10^{-9}$	$2X10^{-4}$
	Ca 47	S	$2X10^{-7}$	$1X10^{-9}$	$6X10^{-9}$	$5X10^{-5}$
		I	$2X10^{-7}$	$1X10^{-3}$	$6X10^{-9}$	$3X10^{-5}$
Californium 98	Cf 249	S	$2X10^{-12}$	$1X10^{-4}$	$5X10^{-14}$	$4X10^{-6}$
		I	$1X10^{-10}$	$7X10^{-4}$	$3X10^{-12}$	$2X10^{-5}$
	Cf 250	S	$5X10^{-12}$	$4X10^{-4}$	$2X10^{-13}$	$1X10^{-5}$
		I	$1X10^{-10}$	$7X10^{-4}$	$3X10^{-12}$	$3X10^{-5}$
	Cf 252	S	$2X10^{-11}$	$7X10^{-4}$	$7X10^{-13}$	$2X10^{-5}$
		I	$1X10^{-10}$	$7X10^{-4}$	$4X10^{-12}$	$2X10^{-5}$
Carbon 6	C 14	S	$4X10^{-6}$	$2X10^{-2}$	$1X10^{-7}$	$8X10^{-4}$
	(CO_2)	Sub	$5X10^{-5}$	-----	$1X10^{-6}$	-----
Cerium 58	Ce 141	S	$4X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$9X10^{-5}$
		I	$2X10^{-7}$	$3X10^{-3}$	$5X10^{-9}$	$9X10^{-5}$
	Ce 143	S	$3X10^{-7}$	$1X10^{-3}$	$9X10^{-9}$	$4X10^{-5}$
		I	$2X10^{-7}$	$1X10^{-3}$	$7X10^{-9}$	$4X10^{-5}$

CONCENTRATION OF RADIOACTIVE MATERIALS
IN AIR AND WATER ABOVE NATURAL BACKGROUND
(See notes at end of appendix)
(Cont.)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week Column 1 Air (μc/ml)	Table I 40 Hour Week Column 2 Water (μc/ml)	Table II 168 Hour Week Column 1 Air (μc/ml)	Table II 168 Hour Week Column 2 Water (μc/ml)
Cerium 58........	Ce 144	S	$1X10^{-8}$	$3X10^{-4}$	$3X10^{-10}$	$1X10^{-5}$
		I	$6X10^{-9}$	$3X10^{-4}$	$2X10^{-10}$	$1X10^{-5}$
Cesium 55........	Cs 131	S	$1X10^{-5}$	$7X10^{-2}$	$4X10^{-7}$	$2X10^{-3}$
		I	$3X10^{-6}$	$3X10^{-2}$	$1X10^{-7}$	$9X10^{-4}$
	Cs 134m	S	$4X10^{-5}$	$2X10^{-1}$	$1X10^{-6}$	$6X10^{-3}$
		I	$6X10^{-6}$	$3X10^{-2}$	$2X10^{-7}$	$1X10^{-3}$
	Cs 134	S	$4X10^{-8}$	$3X10^{-4}$	$1X10^{-9}$	$9X10^{-6}$
		I	$1X10^{-8}$	$1X10^{-3}$	$4X10^{-10}$	$4X10^{-5}$
	Cs 135	S	$5X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
		I	$9X10^{-8}$	$7X10^{-3}$	$3X10^{-9}$	$2X10^{-4}$
	Cs 136	S	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$9X10^{-5}$
		I	$2X10^{-7}$	$2X10^{-3}$	$6X10^{-9}$	$6X10^{-5}$
	Cs 137	S	$6X10^{-8}$	$4X10^{-4}$	$2X10^{-9}$	$2X10^{-5}$
		I	$1X10^{-8}$	$1X10^{-3}$	$5X10^{-10}$	$4X10^{-5}$
Chlorine 17	Cl 17	S	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$8X10^{-5}$
		I	$2X10^{-8}$	$2X10^{-3}$	$8X10^{-10}$	$6X10^{-5}$
	Cl 38	S	$3X10^{-6}$	$1X10^{-2}$	$9X10^{-8}$	$4X10^{-4}$
		I	$2X10^{-6}$	$1X10^{-2}$	$7X10^{-8}$	$4X10^{-4}$
Chromium 24......	Cr 51	S	$1X10^{-5}$	$5X10^{-2}$	$4X10^{-7}$	$2X10^{-3}$
		I	$2X10^{-6}$	$5X10^{-2}$	$8X10^{-8}$	$2X10^{-3}$
Cobalt 27........	Co 57	S	$3X10^{-6}$	$2X10^{-2}$	$1X10^{-7}$	$5X10^{-4}$
		I	$2X10^{-7}$	$1X10^{-2}$	$6X10^{-9}$	$4X10^{-4}$
	Co 58 m	S	$2X10^{-5}$	$8X10^{-2}$	$6X10^{-7}$	$3X10^{-3}$
		I	$9X10^{-6}$	$6X10^{-2}$	$3X10^{-7}$	$2X10^{-3}$
	Co 58	S	$8X10^{-7}$	$4X10^{-3}$	$3X10^{-8}$	$1X10^{-4}$
		I	$5X10^{-8}$	$3X10^{-3}$	$2X10^{-9}$	$9X10^{-5}$
	Co 60	S	$3X10^{-7}$	$1X10^{-3}$	$1X10^{-8}$	$5X10^{-5}$
		I	$9X10^{-9}$	$1X10^{-3}$	$3X10^{-10}$	$3X10^{-5}$
Copper 29........	Cu 64	S	$2X10^{-6}$	$1X10^{-2}$	$7X10^{-8}$	$3X10^{-4}$
		I	$1X10^{-6}$	$6X10^{-3}$	$4X10^{-8}$	$2X10^{-4}$
Curium 96........	Cm 242	S	$1X10^{-10}$	$7X10^{-4}$	$4X10^{-12}$	$2X10^{-5}$
		I	$2X10^{-10}$	$7X10^{-4}$	$6X10^{-12}$	$3X10^{-5}$
	Cm 243	S	$6X10^{-12}$	$1X10^{-4}$	$2X10^{-13}$	$5X10^{-6}$
		I	$1X10^{-10}$	$7X10^{-4}$	$3X10^{-12}$	$2X10^{-5}$

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IN AIR AND WATER ABOVE NATURAL BACKGROUND
(See notes at end of appendix)
(Cont.)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week Column 1 Air (μc/ml)	Table I 40 Hour Week Column 2 Water (μc/ml)	Table II 168 Hour Week Column 1 Air (μc/ml)	Table II 168 Hour Week Column 2 Water (μc/ml)
Curium 96	Cm 244a	S	$9X10^{-12}$	$2X10^{-4}$	$3X10^{-13}$	$7X10^{-6}$
		I	$1X10^{-10}$	$8X10^{-4}$	$3X10^{-12}$	$3X10^{-5}$
	Cm 245	S	$5X10^{-12}$	$1X10^{-4}$	$2X10^{-13}$	$4X10^{-6}$
		I	$1X10^{-10}$	$8X10^{-4}$	$4X10^{-12}$	$3X10^{-5}$
	Cm 246	S	$5X10^{-12}$	$1X10^{-4}$	$2X10^{-13}$	$4X10^{-6}$
		I	$1X10^{-10}$	$8X10^{-4}$	$4X10^{-12}$	$3X10^{-5}$
Dysprosium 66	Dy 165	S	$3X10^{-6}$	$1X10^{-2}$	$9X10^{-8}$	$4X10^{-4}$
		I	$2X10^{-6}$	$1X10^{-2}$	$7X10^{-8}$	$4X10^{-4}$
	Dy 166	S	$2X10^{-7}$	$1X10^{-3}$	$8X10^{-9}$	$4X10^{-5}$
		I	$2X10^{-7}$	$1X10^{-3}$	$7X10^{-9}$	$4X10^{-5}$
Erbium 68	Er 169	S	$6X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$9X10^{-5}$
		I	$4X10^{-7}$	$3X10^{-3}$	$1X10^{-8}$	$9X10^{-5}$
	Er 171	S	$7X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
		I	$6X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
Europium 63	Eu 152	S	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$6X10^{-5}$
	(T/2= 9.2 hrs)	I	$3X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$6X10^{-5}$
	Eu 152	S	$1X10^{-8}$	$2X10^{-3}$	$4X10^{-10}$	$8X10^{-5}$
	(T/2=13 yrs)	I	$2X10^{-8}$	$2X10^{-3}$	$6X10^{-10}$	$8X10^{-5}$
	Eu 154	S	$4X10^{-9}$	$6X10^{-4}$	$1X10^{-10}$	$2X10^{-5}$
		I	$7X10^{-9}$	$6X10^{-4}$	$2X10^{-10}$	$2X10^{-5}$
	Eu 155	S	$9X10^{-8}$	$6X10^{-3}$	$3X10^{-9}$	$2X10^{-5}$
		I	$7X10^{-8}$	$6X10^{-3}$	$3X10^{-9}$	$2X10^{-5}$
Fluorine 9	F 18	S	$5X10^{-6}$	$2X10^{-2}$	$2X10^{-7}$	$8X10^{-4}$
		I	$3X10^{-6}$	$1X10^{-2}$	$9X10^{-8}$	$5X10^{-4}$
Gadolinium 64	Gd 153	S	$2X10^{-7}$	$6X10^{-3}$	$8X10^{-9}$	$2X10^{-4}$
		I	$9X10^{-8}$	$6X10^{-3}$	$3X10^{-9}$	$2X10^{-4}$
	Gd 159	S	$5X10^{-7}$	$2X10^{-3}$	$2X10^{-8}$	$8X10^{-5}$
		I	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$8X10^{-5}$
Gallium 31	Ga 72	S	$2X10^{-7}$	$1X10^{-3}$	$8X10^{-9}$	$4X10^{-5}$
		I	$2X10^{-7}$	$1X10^{-3}$	$6X10^{-9}$	$4X10^{-5}$
Germanium 32	Ge 71	S	$1X10^{-5}$	$5X10^{-2}$	$4X10^{-7}$	$2X10^{-3}$
		I	$6X10^{-6}$	$5X10^{-2}$	$2X10^{-7}$	$2X10^{-3}$
Gold 79	Au 196	S	$1X10^{-6}$	$5X10^{-3}$	$4X10^{-8}$	$2X10^{-4}$
		I	$6X10^{-7}$	$4X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$

CONCENTRATION OF RADIOACTIVE MATERIALS
IN AIR AND WATER ABOVE NATURAL BACKGROUND
(See notes at end of appendix)
(Cont.)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week Column 1 Air (μc/ml)	Table I 40 Hour Week Column 2 Water (μc/ml)	Table II 168 Hour Week Column 1 Air (μc/ml)	Table II 168 Hour Week Column 2 Water (μc/ml)
Gold 79	Au 198	S	$3X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$5X10^{-5}$
		I	$2X10^{-7}$	$1X10^{-3}$	$8X10^{-9}$	$5X10^{-5}$
	Au 199	S	$1X10^{-6}$	$5X10^{-3}$	$4X10^{-8}$	$2X10^{-4}$
		I	$8X10^{-7}$	$4X10^{-3}$	$3X10^{-8}$	$2X10^{-4}$
Hafnium 72	Hf 181	S	$4X10^{-8}$	$2X10^{-3}$	$1X10^{-9}$	$7X10^{-5}$
		I	$7X10^{-8}$	$2X10^{-3}$	$3X10^{-9}$	$7X10^{-5}$
Holmium 67	Ho 166	S	$2X10^{-7}$	$9X10^{-4}$	$7X10^{-9}$	$3X10^{-5}$
		I	$2X10^{-7}$	$9X10^{-4}$	$6X10^{-9}$	$3X10^{-5}$
Hydrogen 1	H 3	S	$5X10^{-6}$	$1X10^{-1}$	$2X10^{-7}$	$3X10^{-3}$
		Sub	$2X10^{-3}$	-----	$4X10^{-5}$	-----
Indium 49	In 113m	S	$8X10^{-6}$	$4X10^{-2}$	$3X10^{-7}$	$1X10^{-3}$
		I	$7X10^{-6}$	$4X10^{-2}$	$2X10^{-7}$	$1X10^{-3}$
	In 114m	S	$1X10^{-7}$	$5X10^{-4}$	$4X10^{-9}$	$2X10^{-5}$
		I	$2X10^{-8}$	$5X10^{-4}$	$7X10^{-10}$	$2X10^{-5}$
	In 115m	S	$2X10^{-6}$	$1X10^{-2}$	$8X10^{-8}$	$4X10^{-4}$
		I	$2X10^{-6}$	$1X10^{-2}$	$6X10^{-8}$	$4X10^{-4}$
	In 115	S	$2X10^{-7}$	$3X10^{-3}$	$9X10^{-9}$	$9X10^{-5}$
		I	$3X10^{-8}$	$3X10^{-3}$	$1X10^{-9}$	$9X10^{-5}$
Iodine 53	I 126	S	$8X10^{-9}$	$5X10^{-5}$	$3X10^{-10}$	$2X10^{-6}$
		I	$3X10^{-7}$	$3X10^{-3}$	$1X10^{-8}$	$9X10^{-5}$
	I 129	S	$2X10^{-9}$	$1X10^{-5}$	$6X10^{-11}$	$4X10^{-7}$
		I	$7X10^{-8}$	$6X10^{-3}$	$2X10^{-9}$	$2X10^{-4}$
	I 131	S	$9X10^{-9}$	$6X10^{-5}$	$3X10^{-10}$	$2X10^{-6}$
		I	$3X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$6X10^{-5}$
	I 132	S	$2X10^{-7}$	$2X10^{-3}$	$8X10^{-9}$	$6X10^{-5}$
		I	$9X10^{-7}$	$5X10^{-3}$	$3X10^{-8}$	$2X10^{-4}$
	I 133	S	$3X10^{-8}$	$2X10^{-4}$	$1X10^{-9}$	$7X10^{-6}$
		I	$2X10^{-7}$	$1X10^{-3}$	$7X10^{-9}$	$4X10^{-5}$

CONCENTRATIONS OF RADIOACTIVE MATERIALS
IN AIR AND WATER ABOVE NATURAL BACKGROUND
(See notes at end of appendix)
(Cont.)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week Column 1 Air (μc/ml)	Table I 40 Hour Week Column 2 Water (μc/ml)	Table II 168 Hour Week Column 1 Air (μc/ml)	Table II 168 Hour Week Column 2 Water (μc/ml)
Iodine 53	I 134	S	$5X10^{-7}$	$4X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
		I	$3X10^{-6}$	$2X10^{-2}$	$1X10^{-7}$	$6X10^{-4}$
	I 135	S	$1X10^{-7}$	$7X10^{-4}$	$4X10^{-9}$	$2X10^{-5}$
		I	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$7X10^{-5}$
Iridium 77	Ir 190	S	$1X10^{-6}$	$6X10^{-3}$	$4X10^{-8}$	$2X10^{-4}$
		I	$4X10^{-7}$	$5X10^{-3}$	$1X10^{-8}$	$2X10^{-4}$
	Ir 192	S	$1X10^{-7}$	$1X10^{-3}$	$4X10^{-9}$	$4X10^{-5}$
		I	$3X10^{-8}$	$1X10^{-3}$	$9X10^{-10}$	$4X10^{-5}$
	Ir 194	S	$2X10^{-7}$	$1X10^{-3}$	$8X10^{-9}$	$3X10^{-5}$
		I	$2X10^{-7}$	$9X10^{-4}$	$5X10^{-9}$	$3X10^{-5}$
Iron 26	Fe 55	S	$9X10^{-7}$	$2X10^{-2}$	$3X10^{-8}$	$8X10^{-4}$
		I	$1X10^{-6}$	$7X10^{-2}$	$3X10^{-8}$	$2X10^{-3}$
	Fe 59	S	$1X10^{-7}$	$2X10^{-3}$	$5X10^{-9}$	$6X10^{-5}$
		I	$5X10^{-8}$	$2X10^{-3}$	$2X10^{-9}$	$5X10^{-5}$
Krypton[2] 36 ...	Kr 85m	Sub	$6X10^{-6}$	-----	$1X10^{-7}$	-----
	Kr 85	Sub	$1X10^{-5}$	-----	$3X10^{-7}$	-----
	Kr 87	Sub	$1X10^{-6}$	-----	$2X10^{-8}$	-----
Lanthanum 57 ..	La 140	S	$2X10^{-7}$	$7X10^{-4}$	$5X10^{-9}$	$2X10^{-5}$
		I	$1X10^{-7}$	$7X10^{-4}$	$4X10^{-9}$	$2X10^{-5}$
Lead 82	Pb 203	S	$3X10^{-6}$	$1X10^{-2}$	$9X10^{-8}$	$4X10^{-4}$
		I	$2X10^{-6}$	$1X10^{-2}$	$6X10^{-8}$	$4X10^{-4}$
	Pb 210	S	$1X10^{-10}$	$4X10^{-6}$	$4X10^{-12}$	$1X10^{-7}$
		I	$2X10^{-10}$	$5X10^{-3}$	$8X10^{-12}$	$2X10^{-4}$
	Pb 212	S	$2X10^{-8}$	$6X10^{-4}$	$6X10^{-10}$	$2X10^{-5}$
		I	$2X10^{-8}$	$5X10^{-4}$	$7X10^{-10}$	$2X10^{-5}$
Lutetium 71 ...	Lu 177	S	$6X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
		I	$5X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
Manganese 25 ..	Mn 52	S	$2X10^{-7}$	$1X10^{-3}$	$7X10^{-9}$	$3X10^{-5}$
		I	$1X10^{-7}$	$9X10^{-4}$	$5X10^{-9}$	$3X10^{-5}$
	Mn 54	S	$4X10^{-7}$	$4X10^{-3}$	$1X10^{-9}$	$1X10^{-4}$
		I	$4X10^{-8}$	$3X10^{-3}$	$1X10^{-9}$	$1X10^{-4}$
	Mn 56	S	$8X10^{-7}$	$4X10^{-3}$	$3X10^{-8}$	$1X10^{-4}$

CONCENTRATIONS OF RADIOACTIVE MATERIALS
IN AIR AND WATER ABOVE NATURAL BACKGROUND
(See notes at end of appendix)
(Cont.)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week Column 1 Air (μc/ml)	Table I 40 Hour Week Column 2 Water (μc/ml)	Table II 168 Hour Week Column 1 Air (μc/ml)	Table II 168 Hour Week Column 2 Water (μc/ml)
Manganese 25	Mn 56	I	$5X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
Mercury 80 . . .	Hg 197m	S	$7X10^{-7}$	$6X10^{-3}$	$3X10^{-8}$	$2X10^{-4}$
		I	$8X10^{-7}$	$5X10^{-3}$	$3X10^{-8}$	$2X10^{-4}$
	Hg 197	S	$1X10^{-6}$	$9X10^{-3}$	$4X10^{-8}$	$3X10^{-4}$
		I	$3X10^{-6}$	$1X10^{-2}$	$9X10^{-8}$	$5X10^{-4}$
	Hg 203	S	$7X10^{-8}$	$5X10^{-4}$	$2X10^{-9}$	$2X10^{-5}$
		I	$1X10^{-7}$	$3X10^{-3}$	$4X10^{-9}$	$1X10^{-4}$
Molybdenum 42 .	Mo 99	S	$7X10^{-7}$	$5X10^{-3}$	$3X10^{-8}$	$2X10^{-4}$
		I	$2X10^{-7}$	$1X10^{-3}$	$7X10^{-9}$	$4X10^{-5}$
Neodymium 60 . .	Nd 144	S	$8X10^{-11}$	$2X10^{-3}$	$3X10^{-12}$	$7X10^{-5}$
		I	$3X10^{-10}$	$2X10^{-3}$	$1X10^{-11}$	$8X10^{-5}$
	Nd 147	S	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$6X10^{-5}$
		I	$2X10^{-7}$	$2X10^{-3}$	$8X10^{-9}$	$6X10^{-5}$
	Nd 149	S	$2X10^{-6}$	$8X10^{-3}$	$6X10^{-8}$	$3X10^{-4}$
		I	$1X10^{-6}$	$8X10^{-3}$	$5X10^{-8}$	$3X10^{-4}$
Neptunium 93 . .	Np 237	S	$4X10^{-12}$	$9X10^{-5}$	$1X10^{-13}$	$3X10^{-6}$
		I	$1X10^{-10}$	$9X10^{-4}$	$4X10^{-12}$	$3X10^{-5}$
	Np 239	S	$8X10^{-7}$	$4X10^{-3}$	$3X10^{-8}$	$1X10^{-4}$
		I	$7X10^{-7}$	$4X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
Nickel 28	Ni 59	S	$5X10^{-7}$	$6X10^{-3}$	$2X10^{-8}$	$2X10^{-4}$
		I	$8X10^{-7}$	$6X10^{-2}$	$3X10^{-8}$	$2X10^{-3}$
	Ni 63	S	$6X10^{-8}$	$8X10^{-4}$	$2X10^{-9}$	$3X10^{-5}$
		I	$3X10^{-7}$	$2X10^{-2}$	$1X10^{-8}$	$7X10^{-4}$
	Ni 65	S	$9X10^{-7}$	$4X10^{-3}$	$3X10^{-8}$	$1X10^{-4}$
		I	$5X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
Niobium (Columbium) 41	Nb 93m	S	$1X10^{-7}$	$1X10^{-2}$	$4X10^{-9}$	$4X10^{-4}$
		I	$2X10^{-7}$	$1X10^{-2}$	$5X10^{-9}$	$4X10^{-4}$
	Nb 95	S	$5X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
		I	$1X10^{-7}$	$3X10^{-3}$	$3X10^{-9}$	$1X10^{-4}$
	Nb 97	S	$6X10^{-6}$	$3X10^{-2}$	$2X10^{-7}$	$9X10^{-4}$
		I	$5X10^{-6}$	$3X10^{-2}$	$2X10^{-7}$	$9X10^{-4}$
Osmium 76	Os 185	S	$5X10^{-7}$	$2X10^{-3}$	$2X10^{-8}$	$7X10^{-5}$
		I	$5X10^{-8}$	$2X10^{-3}$	$2X10^{-9}$	$7X10^{-5}$

CONCENTRATIONS OF RADIOACTIVE MATERIALS
IN AIR AND WATER ABOVE NATURAL BACKGROUND
(See notes at end of appendix)
(Cont.)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week		Table II 168 Hour Week	
			Column 1 Air (μc/ml)	Column 2 Water (μc/ml)	Column 1 Air (μc/ml)	Column 2 Water (μc/ml)
Osmium 76	Os 191m	S	$2X10^{-5}$	$7X10^{-2}$	$6X10^{-7}$	$3X10^{-6}$
		I	$9X10^{-6}$	$7X10^{-2}$	$3X10^{-7}$	$2X10^{-3}$
	Os 191	S	$1X10^{-6}$	$5X10^{-3}$	$4X10^{-8}$	$2X10^{-4}$
		I	$4X10^{-7}$	$5X10^{-3}$	$1X10^{-8}$	$2X10^{-4}$
	Os 193	S	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$6X10^{-5}$
		I	$3X10^{-7}$	$2X10^{-3}$	$9X10^{-9}$	$5X10^{-5}$
Palladium 46	Pd 103	S	$1X10^{-6}$	$1X10^{-2}$	$5X10^{-8}$	$3X10^{-4}$
		I	$7X10^{-7}$	$8X10^{-3}$	$3X10^{-8}$	$3X10^{-4}$
	Pd 109	S	$6X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$9X10^{-5}$
		I	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$7X10^{-5}$
Phosphorus 15	P 32	S	$7X10^{-8}$	$5X10^{-4}$	$2X10^{-9}$	$2X10^{-5}$
		I	$8X10^{-8}$	$7X10^{-4}$	$3X10^{-9}$	$2X10^{-5}$
Platinum 78	Pt 191	S	$8X10^{-7}$	$4X10^{-3}$	$3X10^{-8}$	$1X10^{-4}$
		I	$6X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
	Pt 193m	S	$7X10^{-6}$	$3X10^{-2}$	$2X10^{-7}$	$1X10^{-3}$
		I	$5X10^{-6}$	$3X10^{-2}$	$2X10^{-7}$	$1X10^{-3}$
	Pt 197m	S	$6X10^{-6}$	$3X10^{-2}$	$2X10^{-7}$	$1X10^{-3}$
		I	$5X10^{-6}$	$3X10^{-2}$	$2X10^{-7}$	$9X10^{-4}$
	Pt 197	S	$8X10^{-7}$	$4X10^{-3}$	$3X10^{-8}$	$1X10^{-4}$
		I	$6X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
Plutonium 94	Pu 238	S	$2X10^{-12}$	$1X10^{-4}$	$7X10^{-14}$	$5X10^{-6}$
		I	$3X10^{-11}$	$8X10^{-4}$	$1X10^{-12}$	$3X10^{-5}$
	Pu 239	S	$2X10^{-12}$	$1X10^{-4}$	$6X10^{-14}$	$5X10^{-6}$
		I	$4X10^{-11}$	$8X10^{-4}$	$1X10^{-12}$	$3X10^{-5}$
	Pu 240	S	$2X10^{-12}$	$1X10^{-4}$	$6X10^{-14}$	$5X10^{-6}$
		I	$4X10^{-11}$	$8X10^{-4}$	$1X10^{-12}$	$3X10^{-5}$
	Pu 241	S	$9X10^{-11}$	$7X10^{-3}$	$3X10^{-12}$	$2X10^{-4}$
		I	$4X10^{-8}$	$4X10^{-2}$	$1X10^{-9}$	$1X10^{-3}$
	Pu 242	S	$2X10^{-12}$	$1X10^{-4}$	$6X10^{-14}$	$5X10^{-6}$
		I	$4X10^{-11}$	$9X10^{-4}$	$1X10^{-12}$	$3X10^{-5}$
Polonium 84	Po 210	S	$5X10^{-10}$	$2X10^{-5}$	$2X10^{-11}$	$7X10^{-7}$
		I	$2X10^{-10}$	$8X10^{-4}$	$7X10^{-12}$	$3X10^{-5}$

CONCENTRATIONS OF RADIOACTIVE MATERIALS
IN AIR AND WATER ABOVE NATURAL BACKGROUND
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(Cont.)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week Column 1 Air (μc/ml)	Table I 40 Hour Week Column 2 Water (μc/ml)	Table II 168 Hour Week Column 1 Air (μc/ml)	Table II 168 Hour Week Column 2 Water (μc/ml)
Potassium 19	K 42	S	$2X10^{-6}$	$9X10^{-3}$	$7X10^{-8}$	$3X10^{-4}$
		I	$1X10^{-7}$	$6X10^{-4}$	$4X10^{-9}$	$2X10^{-5}$
Praseodymium 59	Pr 142	S	$2X10^{-7}$	$9X10^{-4}$	$7X10^{-9}$	$3X10^{-5}$
		I	$2X10^{-7}$	$9X10^{-4}$	$5X10^{-9}$	$3X10^{-5}$
	Pr 143	S	$3X10^{-7}$	$1X10^{-3}$	$1X10^{-8}$	$5X10^{-5}$
		I	$2X10^{-7}$	$1X10^{-3}$	$6X10^{-9}$	$5X10^{-5}$
Promethium 61	Pm 147	S	$6X10^{-8}$	$6X10^{-3}$	$2X10^{-9}$	$2X10^{-4}$
		I	$1X10^{-7}$	$6X10^{-3}$	$3X10^{-9}$	$2X10^{-4}$
	Pm 149	S	$3X10^{-7}$	$1X10^{-3}$	$1X10^{-8}$	$4X10^{-5}$
		I	$2X10^{-7}$	$1X10^{-3}$	$8X10^{-9}$	$4X10^{-5}$
Protoactinium 91	Pa 230	S	$2X10^{-9}$	$7X10^{-3}$	$6X10^{-11}$	$2X10^{-4}$
		I	$8X10^{-10}$	$7X10^{-3}$	$3X10^{-11}$	$2X10^{-4}$
	Pa 231	S	$1X10^{-12}$	$3X10^{-5}$	$4X10^{-14}$	$9X10^{-7}$
		I	$1X10^{-10}$	$8X10^{-4}$	$4X10^{-12}$	$2X10^{-5}$
	Pa 233	S	$6X10^{-7}$	$4X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
		I	$2X10^{-7}$	$3X10^{-3}$	$6X10^{-9}$	$1X10^{-4}$
Radium 88	Ra 223	S	$2X10^{-9}$	$2X10^{-5}$	$6X10^{-11}$	$7X10^{-7}$
		I	$2X10^{-10}$	$1X10^{-4}$	$8X10^{-12}$	$4X10^{-6}$
	Ra 224	S	$5X10^{-9}$	$7X10^{-5}$	$2X10^{-10}$	$2X10^{-6}$
		I	$7X10^{-10}$	$2X10^{-4}$	$2X10^{-11}$	$5X10^{-6}$
	Ra 226	S	$3X10^{-11}$	$4X10^{-7}$	$1X10^{-12}$	$1X10^{-8}$
		I	$5X10^{-11}$	$9X10^{-4}$	$2X10^{-12}$	$3X10^{-5}$
	Ra 228	S	$7X10^{-11}$	$8X10^{-7}$	$2X10^{-12}$	$3X10^{-8}$
		I	$4X10^{-11}$	$7X10^{-4}$	$1X10^{-12}$	$3X10^{-5}$
Radon 86	Rn 220	S	$3X10^{-7}$	-----	$1X10^{-8}$	-----
		I	-----	-----	-----	-----
	Rn 222	S	$1X10^{-7}$	-----	$3X10^{-9}$	-----
Rhenium 75	Re 183	S	$3X10^{-6}$	$2X10^{-2}$	$9X10^{-8}$	$6X10^{-4}$
		I	$2X10^{-7}$	$8X10^{-3}$	$5X10^{-9}$	$3X10^{-4}$
	Re 186	S	$6X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$9X10^{-5}$
		I	$2X10^{-7}$	$1X10^{-3}$	$8X10^{-9}$	$5X10^{-5}$
	Re 187	S	$9X10^{-6}$	$7X10^{-2}$	$3X10^{-7}$	$3X10^{-3}$
		I	$5X10^{-7}$	$4X10^{-2}$	$2X10^{-8}$	$2X10^{-3}$

CONCENTRATIONS OF RADIOACTIVE MATERIALS IN AIR AND WATER ABOVE NATURAL BACKGROUND

(See notes at end of appendix)

(Cont.)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week Column 1 Air (μc/ml)	Table I 40 Hour Week Column 2 Water (μc/ml)	Table II 168 Hour Week Column 1 Air (μc/ml)	Table II 168 Hour Week Column 2 Water (μc/ml)
	Re 188	S	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$6X10^{-5}$
		I	$2X10^{-7}$	$9X10^{-4}$	$6X10^{-9}$	$3X10^{-5}$
Rhodium 45	Rh 103m	S	$8X10^{-5}$	$4X10^{-1}$	$3X10^{-6}$	$1X10^{-2}$
		I	$6X10^{-5}$	$3X10^{-1}$	$2X10^{-6}$	$1X10^{-2}$
	Rh 105	S	$8X10^{-7}$	$4X10^{-3}$	$3X10^{-8}$	$1X10^{-4}$
		I	$5X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
Rubidium 37	Rb 86	S	$3X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$7X10^{-5}$
		I	$7X10^{-8}$	$7X10^{-4}$	$2X10^{-9}$	$2X10^{-5}$
	Rb 87	S	$5X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
		I	$7X10^{-8}$	$5X10^{-3}$	$2X10^{-9}$	$2X10^{-4}$
Ruthenium 44	Ru 97	S	$2X10^{-6}$	$1X10^{-2}$	$8X10^{-8}$	$4X10^{-4}$
		I	$2X10^{-6}$	$1X10^{-2}$	$6X10^{-8}$	$3X10^{-4}$
	Ru 103	S	$5X10^{-7}$	$2X10^{-3}$	$2X10^{-8}$	$8X10^{-5}$
		I	$8X10^{-8}$	$2X10^{-3}$	$3X10^{-9}$	$8X10^{-5}$
	Ru 105	S	$7X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
		I	$5X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
	Ru 106	S	$8X10^{-8}$	$4X10^{-4}$	$3X10^{-9}$	$1X10^{-5}$
		I	$6X10^{-9}$	$3X10^{-4}$	$2X10^{-10}$	$1X10^{-5}$
Samarium 62	Sm 147	S	$7X10^{-11}$	$2X10^{-3}$	$2X10^{-12}$	$6X10^{-5}$
		I	$3X10^{-10}$	$2X10^{-3}$	$9X10^{-12}$	$7X10^{-5}$
	Sm 151	S	$6X10^{-8}$	$1X10^{-2}$	$2X10^{-9}$	$4X10^{-4}$
		I	$1X10^{-7}$	$1X10^{-2}$	$5X10^{-9}$	$4X10^{-4}$
	Sm 153	S	$5X10^{-7}$	$2X10^{-3}$	$2X10^{-8}$	$8X10^{-5}$
		I	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$8X10^{-5}$
Scandium 21	Sc 46	S	$2X10^{-7}$	$1X10^{-3}$	$8X10^{-9}$	$4X10^{-5}$
		I	$2X10^{-8}$	$1X10^{-3}$	$8X10^{-10}$	$4X10^{-5}$
	Sc 47	S	$6X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$9X10^{-5}$
		I	$5X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$9X10^{-5}$
	Sc 48	S	$2X10^{-7}$	$8X10^{-4}$	$6X10^{-9}$	$3X10^{-5}$
		I	$1X10^{-7}$	$8X10^{-4}$	$5X10^{-9}$	$3X10^{-5}$
Selenium 34	Se 75	S	$1X10^{-6}$	$9X10^{-3}$	$4X10^{-8}$	$3X10^{-4}$
		I	$1X10^{-7}$	$8X10^{-3}$	$4X10^{-9}$	$3X10^{-4}$
Silicon 14	Si 31	S	$6X10^{-6}$	$3X10^{-2}$	$2X10^{-7}$	$9X10^{-4}$
		I	$1X10^{-6}$	$6X10^{-3}$	$3X10^{-8}$	$2X10^{-4}$

CONCENTRATIONS OF RADIOACTIVE MATERIALS
IN AIR AND WATER ABOVE NATURAL BACKGROUND
(See notes at end of appendix)
(Cont.)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week Column 1 Air (μc/ml)	Table I 40 Hour Week Column 2 Water (μc/ml)	Table II 168 Hour Week Column 1 Air (μc/ml)	Table II 168 Hour Week Column 2 Water (μc/ml)
Silver 47	Ag 105	S	$6X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
		I	$8X10^{-8}$	$3X10^{-3}$	$3X10^{-9}$	$1X10^{-4}$
	Ag 110m	S	$2X10^{-7}$	$9X10^{-4}$	$7X10^{-9}$	$3X10^{-5}$
		I	$1X10^{-8}$	$9X10^{-4}$	$3X10^{-10}$	$3X10^{-5}$
	Ag 111	S	$3X10^{-7}$	$1X10^{-3}$	$1X10^{-8}$	$4X10^{-5}$
		I	$2X10^{-7}$	$1X10^{-3}$	$8X10^{-9}$	$4X10^{-5}$
Sodium 11	Na 22	S	$2X10^{-7}$	$1X10^{-3}$	$6X10^{-9}$	$4X10^{-5}$
		I	$9X10^{-9}$	$9X10^{-4}$	$3X10^{-10}$	$3X10^{-5}$
	Na 24	S	$1X10^{-6}$	$6X10^{-3}$	$4X10^{-8}$	$2X10^{-4}$
		I	$1X10^{-7}$	$8X10^{-4}$	$5X10^{-9}$	$3X10^{-5}$
Strontium 38	Sr 85m	S	$4X10^{-5}$	$2X10^{-1}$	$1X10^{-6}$	$7X10^{-3}$
		I	$3X10^{-5}$	$2X10^{-1}$	$1X10^{-6}$	$7X10^{-3}$
	Sr 85	S	$2X10^{-7}$	$3X10^{-3}$	$8X10^{-9}$	$1X10^{-4}$
		I	$1X10^{-7}$	$5X10^{-3}$	$4X10^{-9}$	$2X10^{-4}$
	Sr 89	S	$3X10^{-8}$	$3X10^{-4}$	$1X10^{-9}$	$1X10^{-5}$
		I	$4X10^{-8}$	$8X10^{-4}$	$1X10^{-9}$	$3X10^{-5}$
	Sr 90	S	$3X10^{-10}$	$4X10^{-6}$	$1X10^{-11}$	$1X10^{-7}$
		I	$5X10^{-9}$	$1X10^{-3}$	$2X10^{-10}$	$4X10^{-5}$
	Sr 91	S	$4X10^{-7}$	$2X10^{-3}$	$2X10^{-8}$	$7X10^{-5}$
		I	$3X10^{-7}$	$1X10^{-3}$	$9X10^{-9}$	$5X10^{-5}$
	Sr 92	S	$4x10^{-7}$	$2X10^{-3}$	$2X10^{-8}$	$7X10^{-5}$
		I	$3X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$6X10^{-5}$
Sulfur 16	S 35	S	$3X10^{-7}$	$2X10^{-3}$	$9X10^{-9}$	$6X10^{-5}$
		I	$3X10^{-7}$	$8X10^{-3}$	$9X10^{-9}$	$3X10^{-4}$
Tantalum 73	Ta 182	S	$4X10^{-8}$	$1X10^{-3}$	$1X10^{-9}$	$4X10^{-5}$
		I	$2X10^{-8}$	$1X10^{-3}$	$7X10^{-10}$	$4X10^{-5}$
Technetium 43	Tc 96m	S	$8X10^{-5}$	$4X10^{-1}$	$3X10^{-6}$	$1X10^{-2}$
		I	$3X10^{-5}$	$3X10^{-1}$	$1X10^{-6}$	$1X10^{-2}$
	Tc 96	S	$6X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
		I	$2X10^{-7}$	$1X10^{-3}$	$8X10^{-9}$	$5X10^{-5}$
	Tc 97m	S	$2X10^{-6}$	$1X10^{-2}$	$8X10^{-8}$	$4X10^{-4}$

CONCENTRATIONS OF RADIOACTIVE MATERIALS
IN AIR AND WATER ABOVE NATURAL BACKGROUND
(See notes at end of appendix)
(Cont.)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week Column 1 Air ($\mu c/ml$)	Table I 40 Hour Week Column 2 Water ($\mu c/ml$)	Table II 168 Hour Week Column 1 Air ($\mu c/ml$)	Table II 168 Hour Week Column 2 Water ($\mu c/ml$)
Technetium 43	Tc 97m	I	$2X10^{-7}$	$5X10^{-3}$	$5X10^{-9}$	$2X10^{-4}$
	Tc 97	S	$1X10^{-5}$	$5X10^{-2}$	$4X10^{-7}$	$2X10^{-3}$
		I	$3X10^{-7}$	$2X10^{-2}$	$1X10^{-8}$	$8X10^{-4}$
	Tc 99m	S	$4X10^{-5}$	$2X10^{-1}$	$1X10^{-6}$	$6X10^{-3}$
		I	$1X10^{-5}$	$8X10^{-2}$	$5X10^{-7}$	$3X10^{-3}$
	Tc 99	S	$2X10^{-6}$	$1X10^{-2}$	$7X10^{-8}$	$3X10^{-4}$
		I	$6X10^{-8}$	$5X10^{-3}$	$2X10^{-9}$	$2X10^{-4}$
Tellurium 52	Te 125m	S	$4X10^{-7}$	$5X10^{-3}$	$1X10^{-8}$	$2X10^{-4}$
		I	$1X10^{-7}$	$3X10^{-3}$	$4X10^{-9}$	$1X10^{-4}$
	Te 127m	S	$1X10^{-7}$	$2X10^{-3}$	$5X10^{-9}$	$6X10^{-5}$
		I	$4X10^{-8}$	$2X10^{-3}$	$1X10^{-9}$	$5X10^{-5}$
	Te 127	S	$2X10^{-6}$	$8X10^{-3}$	$6X10^{-8}$	$3X10^{-4}$
		I	$9X10^{-7}$	$5X10^{-3}$	$3X10^{-8}$	$2X10^{-4}$
	Te 129m	S	$8X10^{-8}$	$1X10^{-3}$	$3X10^{-9}$	$3X10^{-5}$
		I	$3X10^{-8}$	$6X10^{-4}$	$1X10^{-9}$	$2X10^{-5}$
	Te 129	S	$5X10^{-6}$	$2X10^{-2}$	$2X10^{-7}$	$8X10^{-4}$
		I	$4X10^{-6}$	$2X10^{-2}$	$1X10^{-7}$	$8X10^{-4}$
	Te 131m	S	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$6X10^{-5}$
		I	$2X10^{-7}$	$1X10^{-3}$	$6X10^{-9}$	$4X10^{-5}$
	Te 132	S	$2X10^{-7}$	$9X10^{-4}$	$7X10^{-9}$	$3X10^{-5}$
		I	$1X10^{-7}$	$6X10^{-4}$	$4X10^{-9}$	$2X10^{-5}$
Terbium 65	Tb 160	S	$1X10^{-7}$	$1X10^{-3}$	$3X10^{-9}$	$4X10^{-5}$
		I	$3X10^{-8}$	$1X10^{-3}$	$1X10^{-9}$	$4X10^{-5}$
Thalium 81	Tl 200	S	$3X10^{-6}$	$1X10^{-2}$	$9X10^{-8}$	$4X10^{-4}$
		I	$1X10^{-6}$	$7X10^{-3}$	$4X10^{-8}$	$2X10^{-4}$
	Tl 201	S	$2X10^{-6}$	$9X10^{-3}$	$7X10^{-8}$	$3X10^{-4}$
		I	$9X10^{-7}$	$5X10^{-3}$	$3X10^{-8}$	$2X10^{-4}$
	Tl 202	S	$8X10^{-7}$	$4X10^{-3}$	$3X10^{-8}$	$1X10^{-4}$
		I	$2X10^{-7}$	$2X10^{-3}$	$8X10^{-9}$	$7X10^{-5}$
	Tl 204	S	$6X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
		I	$3X10^{-8}$	$2X10^{-3}$	$9X10^{-10}$	$6X10^{-5}$

CONCENTRATIONS OF RADIOACTIVE MATERIALS
IN AIR AND WATER ABOVE NATURAL BACKGROUND
(See notes at end of appendix)
(Cont.)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week Column 1 Air (μc/ml)	Table I 40 Hour Week Column 2 Water (μc/ml)	Table II 168 Hour Week Column 1 Air (μc/ml)	Table II 168 Hour Week Column 2 Water (μc/ml)
Thorium 90	Th 228	S	$9X10^{-12}$	$2X10^{-4}$	$3X10^{-13}$	$7X10^{-6}$
		I	$6X10^{-12}$	$4X10^{-4}$	$2X10^{-13}$	10^{-6}
	Th 230	S	$2X10^{-12}$	$5X10^{-5}$	$8X10^{-14}$	$2X10^{-6}$
		I	10^{-11}	$9X10^{-4}$	$3X10^{-13}$	$3X10^{-6}$
	Th 232	S	$3X10^{-11}$	$5X10^{-5}$	10^{-12}	$2X10^{-6}$
		I	$3X10^{-11}$	10^{-3}	10^{-12}	$4X10^{-5}$
	Th natural	S	$3X10^{-11}$	$3X10^{-5}$	10^{-12}	10^{-6}
		I	$3X10^{-11}$	$3X10^{-4}$	10^{-12}	10^{-6}
	Th 234	S	$6X10^{-8}$	$5X10^{-4}$	$2X10^{-9}$	$2X10^{-5}$
		I	$3X10^{-8}$	$5X10^{-4}$	10^{-9}	$2X10^{-5}$
Thulium 69	Tm 170	S	$4X10^{-8}$	$1X10^{-3}$	$1X10^{-9}$	$5X10^{-5}$
		I	$3X10^{-8}$	$1X10^{-3}$	$1X10^{-9}$	$5X10^{-5}$
	Tm 171	S	$1X10^{-7}$	$1X10^{-2}$	$4X10^{-9}$	$5X10^{-4}$
		I	$2X10^{-7}$	$1X10^{-2}$	$8X10^{-9}$	$5X10^{-4}$
Tin 50	Sn 113	S	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$9X10^{-5}$
		I	$5X10^{-8}$	$2X10^{-3}$	$2X10^{-9}$	$8X10^{-5}$
	Sn 125	S	$1X10^{-7}$	$5X10^{-4}$	$4X10^{-9}$	$2X10^{-5}$
		I	$8X10^{-8}$	$5X10^{-4}$	$3X10^{-9}$	$2X10^{-5}$
Tungsten (Wolfram) 74	W 181	S	$2X10^{-6}$	$1X10^{-2}$	$8X10^{-8}$	$4X10^{-4}$
		I	$1X10^{-7}$	$1X10^{-2}$	$4X10^{-9}$	$3X10^{-4}$
	W 185	S	$8X10^{-7}$	$4X10^{-3}$	$3X10^{-8}$	$1X10^{-4}$
		I	$1X10^{-7}$	$3X10^{-3}$	$4X10^{-9}$	$1X10^{-6}$
	W 187	S	$4X10^{-7}$	$2X10^{-3}$	$2X10^{-8}$	$7X10^{-5}$
		I	$3X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$6X10^{-5}$
Uranium 92	U 230	S	$3X10^{-10}$	$1X10^{-4}$	$1X10^{-11}$	$5X10^{-6}$
		I	$1X10^{-10}$	$1X10^{-4}$	$4X10^{-12}$	$5X10^{-6}$
	U 232	S	$1X10^{-10}$	$8X10^{-4}$	$3X10^{-12}$	$3X10^{-5}$
		I	$3X10^{-11}$	$8X10^{-4}$	$9X10^{-13}$	$3X10^{-5}$
	U 233	S	$5X10^{-10}$	$9X10^{-4}$	$2X10^{-11}$	$3X10^{-5}$
		I	$1X10^{-10}$	$9X10^{-4}$	$4X10^{-12}$	$3X10^{-5}$
	U 234	S	$6X10^{-10}$	$9X10^{-4}$	$2X10^{-11}$	$3X10^{-5}$
		I	$1X10^{-10}$	$9X10^{-4}$	$4X10^{-12}$	$3X10^{-5}$
	U 235	S	$5X10^{-10}$	$8X10^{-4}$	$2X10^{-11}$	$3X10^{-5}$
		I	$1X10^{-10}$	$8X10^{-4}$	$4X10^{-12}$	$3X10^{-5}$

CONCENTRATIONS OF RADIOACTIVE MATERIALS
IN AIR AND WATER ABOVE NATURAL BACKGROUND
(See notes at end of appendix)
(Cont.)

Element (atomic number)	Isotope[1]		Table I 40 Hour Week		Table II 168 Hour Week	
			Column 1 Air (μc/ml)	Column 2 Water (μc/ml)	Column 1 Air (μc/ml)	Column 2 Water (μc/ml)
Uranium 92	U 236	S	$6X10^{-10}$	$1X10^{-3}$	$2X10^{-11}$	$3X10^{-5}$
		I	$1X10^{-10}$	$1X10^{-3}$	$4X10^{-12}$	$3X10^{-5}$
	U 238	S	$7X10^{-11}$	$1X10^{-3}$	$3X10^{-12}$	$4X10^{-5}$
		I	$1X10^{-10}$	$1X10^{-3}$	$5X10^{-12}$	$4X10^{-5}$
	U natural	S	$7X10^{-11}$	$5X10^{-4}$	$3X10^{-12}$	$2X10^{-5}$
		I	$6X10^{-11}$	$5X10^{-4}$	$2X10^{-12}$	$2X10^{-5}$
Vanadium 23	V 48	S	$2X10^{-7}$	$9X10^{-4}$	$6X10^{-9}$	$3X10^{-5}$
		I	$6X10^{-8}$	$8X10^{-4}$	$2X10^{-9}$	$3X10^{-5}$
Xenon 54	Xe 131m	Sub	$2X10^{-5}$	-----	$4X10^{-7}$	-----
	Xe 133	Sub	$1X10^{-5}$	-----	$3X10^{-7}$	-----
	Xe 135	Sub	$4X10^{-6}$	-----	$1X10^{-7}$	-----
Ytterbium 70	Yb 175	S	$7X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
		I	$6X10^{-7}$	$3X10^{-3}$	$2X10^{-8}$	$1X10^{-4}$
Yttrium 39	Y 90	S	$1X10^{-7}$	$6X10^{-4}$	$4X10^{-9}$	$2X10^{-5}$
		I	$1X10^{-7}$	$6X10^{-4}$	$3X10^{-9}$	$2X10^{-5}$
	Y 91m	S	$2X10^{-5}$	$1X10^{-1}$	$8X10^{-7}$	$3X10^{-3}$
		I	$2X10^{-5}$	$1X10^{-1}$	$6X10^{-7}$	$3X10^{-3}$
	Y 91	S	$4X10^{-8}$	$8X10^{-4}$	$1X10^{-9}$	$3X10^{-5}$
		I	$3X10^{-8}$	$8X10^{-4}$	$1X10^{-9}$	$3X10^{-5}$
	Y 92	S	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$6X10^{-5}$
		I	$3X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$6X10^{-5}$
	Y 93	S	$2X10^{-7}$	$8X10^{-4}$	$5X10^{-9}$	$3X10^{-5}$
		I	$1X10^{-7}$	$8X10^{-4}$	$5X10^{-9}$	$3X10^{-5}$
Zinc 30	Zn 65	S	$1X10^{-7}$	$3X10^{-3}$	$4X10^{-9}$	$1X10^{-4}$
		I	$6X10^{-8}$	$5X10^{-3}$	$2X10^{-9}$	$2X10^{-5}$
	Zn 69m	S	$4X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$7X10^{-5}$
		I	$3X10^{-7}$	$2X10^{-3}$	$1X10^{-8}$	$6X10^{-5}$
	Zn 69	S	$7X10^{-6}$	$5X10^{-2}$	$2X10^{-7}$	$2X10^{-3}$
		I	$9X10^{-6}$	$5X10^{-2}$	$3X10^{-7}$	$2X10^{-3}$
Zirconium 40	Zr 93	S	$1X10^{-7}$	$2X10^{-2}$	$4X10^{-9}$	$8X10^{-4}$
		I	$3X10^{-7}$	$2X10^{-2}$	$1X10^{-8}$	$8X10^{-4}$
	Zr 95	S	$1X10^{-7}$	$2X10^{-3}$	$4X10^{-9}$	$6X10^{-5}$
		I	$3X10^{-8}$	$2X10^{-3}$	$1X10^{-9}$	$6X10^{-5}$
	Zr 97	S	$1X10^{-7}$	$5X10^{-4}$	$4X10^{-9}$	$2X10^{-5}$
		I	$9X10^{-8}$	$5X10^{-4}$	$3X10^{-9}$	$2X10^{-5}$

CONCENTRATIONS OF RADIOACTIVE MATERIALS IN AIR AND WATER ABOVE NATURAL BACKGROUND
(Notes)

[1] Soluble (S); Insoluble (I).

[2] "Sub" means that values given are for submersion in an infinite cloud of gaseous material.

NOTE: In any case where there is a mixture in air or water of more than one radionuclide, the limiting values for purposes of this Appendix should determined as follows:

1. If the identity and concentration of each radionuclide in the mixture are known, the limiting values should be derived as follows: Determine, for each radionuclide in the mixture, the ratio between the quantity present in the mixture and the limit otherwise established in Appendix B for the specific radionuclide when not in a mixture. The sum of such ratios for all the radionuclides in the mixture may not exceed "1" (i.e. "unity").

EXAMPLE: If radionuclides A, B, and C are present in concentration C_A, C_B, C_C, and if the applicable MPCs, are MPC_A, and MPC_B, and MPC_C, respectively, then the concentrations shall be limited so that the following relationship exists:

$$\frac{C_A}{MPC} + \frac{C_B}{MPC} + \frac{C_C}{MPC} = 1$$

2. If either the identity or the concentration of any radionuclide in the mixture is not known, the limiting values for purposes of Appendix B shall be:

a. For purposes of Table I, Col. 1-$1X10^{-12}$
b. For purposes of Table I, Col. 2-$3X10^{-7}$
c. For purposes of Table II, Col. 1-$4X10^{-14}$
d. For purposes of Table II, Col. 2-$1X10^{-8}$

APPENDIX C

LABELING LEVELS FOR RADIOACTIVE MATERIALS, TRACER STUDIES

Material	Microcuries	Material	Microcuries
Ag105	1	Pd103+Rh103	50
Ag111	10	Pd109	10
As76, As77	10	Pm147	10
Au198	10	Po210	0.1
Au199	10	Pr143	10
Ba140+La140	1	Pu239	1
Be7	50	Ra226	0.1
C14	50	Rb86	10
Ca45	10	Re186	10
Cd109+Ag109	10	Rh105	10
Ce144+Pr144	1	Ru106+Rh106	1
Cl36	1	S35	50
Co60	1	Sb124	1
Cr51	50	Sx46	1
Cs137+Ba137	1	Sm153	10
Cu64	50	Sn113	10
Eu154	1	Sr89	1
F18	50	Sr90+Y90	0.1
Fe55	50	Ta182	10
Fe59	1	Tc96	1
Ga72	10	Tc99	1
Ge71	50	Te127	10
H3(HTO or H320)	250	Te129	1
I131	10	Th (natural)	50
In114	1	Tl204	50
Ir192	10	Tritium. See H3	250
K42	10	U (natural)	50
La140	10	U233	1
Mn52	1	U234-U235	50
Mn56	50	V48	1
Mo99	10	W185	10
Na22	10	Y90	1
Na24	10	Y91	1
Nb95	10	Zn65	10
Ni59	1	Unidentified radioactive materials or any of the above in unknown mixtures	0.1
Ni63	1		
P32	10		

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