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Bioenvironmental Engineering Journeyman

Volume 4B. Occupational and Environmental Health Risk Assessment: Radiation

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Author: Mr. Mark H. Hanson
United States Air Force School of Aerospace Medicine (USAFSAM)
Bioenvironmental Education and Training Branch
2510 Fifth Street, Building 840
Wright-Patterson Air Force Base, Ohio 45433
DSN: 798-3010
E-mail address: mark.hanson.12@us.af.mil

Instructional Systems Specialist: Todd Knowles

Editor: Maxine Baldwin

Air Force Career Development Academy (AFCDA)
Air University (AETC)
Maxwell AFB-Gunter Annex, Alabama

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THIS Fourth volume, part B, of Career Development Course (CDC) 4B051, *Bioenvironmental Engineering Journeyman*, covers foundational concepts, information, and procedures regarding radiation physics as well as bioenvironmental engineering's (BEE) role and the duties associated in dealing with radiation safety.

Unit 1 introduces the general principles applied to electromagnetic waves and the effects of energy on the human body as they relate to health physics.

Unit 2 presents a view of the Air Force personnel dosimetry program, including the use of radiation detection and monitoring equipment, preparation/shipment of collected samples, and the methodology and formulae used when performing radiation calculations.

Unit 3 discusses radiation protection principles. The topics included are as low as reasonably achievable (ALARA) training, hazard controls, hazards associated with uranium, radon gas monitoring, and disposal of radioactive waste.

Unit 4 provides a discourse on the topic of nuclear enterprise. The unit covers the theory and operation of nuclear weapons; types of nuclear weapons; incidents, accidents, and threats associated with nuclear weapons; and BEE's role in the nuclear enterprise program.

A glossary is included for your use.

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For Guard and Reserve personnel, this volume is valued at 20 hours and 5 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

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Unit 1. Health Physics

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IONIZING RADIATION is a general term applied to both electromagnetic waves and/or particulate radiation capable of producing ions by interaction with matter. As the science of physics deals with matter and energy and their interactions in general, *health physics* is specifically concerned with the effects of energy upon the human body. An examination of these effects and their causes will give a better appreciation for the importance of controlling exposures. It also provides a basis for radiation protection guidance.

622. Radioactive decay

All elements with an atomic or proton number (Z) of 84 or higher are unstable. Such elements are known as *radioactive* and have unstable (radioactive) isotopes. A delicate balance of forces among the nuclear particles keeps the nucleus stable. Changes in the number, arrangement, or energy of the nucleons can result in an unstable condition. These unstable combinations (isotopes) are called *radionuclides*. Elements that are in an *unstable* state and trying to achieve stability will emit particles or energy. The nucleus emits radiation and transforms the unstable atom into a different nuclide. In this process of trying to become stable, these materials must go through at least one, and often many steps, throwing off particles or energy at each step. This process is known as *radioactive decay*.

There are structural criteria that must be met for a nucleus to be stable. When such criteria are not met, a nucleus attempts to reach stability by one or more steps known as *nuclear decay*, *disintegration*, or *transformation.* Each of these terms has been used to describe the processes taking place within a radioactive atom. The term disintegration, although still used with a few other radioactivity terms such as *disintegrations per second (dps)*, has been largely replaced by the term *transformation* because of the latter's broader applicability. The steps taken by an unstable nucleus, ejection of a particle or excess energy, are due to proton (p)/neutron (n) arrangements and some complicated considerations involving binding energy and quantum-mechanical principles. The simpler aspects of protons and neutrons best fit our needs in understanding nuclear stability. The positively charged protons have a tendency to tear the nucleus apart because of their relatively long-range repulsive electromagnetic force, known as coulomb (C) force. Short-range forces between protons and neutrons are not completely understood but tend to act as attractive forces. The neutrons seem to be buffers between the repelling protons. Therefore, there are only certain arrangements of protons and neutrons that can produce a stable nucleus.

For lighter elements, in which the coulomb forces are insignificant compared to the short range forces, optimum nuclear stability is achieved when there are equal numbers of protons and neutrons. However, coulomb forces become more and more important as the number of protons increases above 20. As these repulsive forces increase, stability decreases, and an excess of neutrons is required for a stable nucleus. That is, the ratio of neutrons to protons, the *n:p ratio*, must increase gradually. This works out very well until atomic number 83, or bismuth (Bi), is reached; where the n:p ratio needed for stability exceeds 1.5:1. There are no completely stable nuclides above Bi–209, which has 126 neutrons and 83 protons for an n:p ratio of about 1.518:1. Several different n:p ratios can exist for a given atomic number or mass number (A) that will give a stable nucleus. A nucleus that does not fall within its necessary n:p ratio range seeks an alteration of its neutron and proton arrangement.

When a radionuclide transforms, a "transmutation" occurs. With each transmutation, the nucleus is in an excited state and must release energy. Because the number of protons within the nucleus changes, the decay product, called the daughter or progeny, becomes an atom of a new element with chemical properties entirely unlike the original parent atom. The following modes of decay allow the nucleus to do just that:

- Alpha (α) decay
- Beta (β) decay
- Electron capture (EC).
- Isomeric transition.
- Neutrons.
- Fission.

Alpha decay

During alpha (α) decay, an atom's nucleus sheds an alpha particle (two protons and two neutrons), changing it from one element to another. An alpha particle, which is identical to a helium (He) nucleus, is heavy and slow compared to other types of radiation. This, combined with its double positive charge, makes alpha the most ionizing radiation; it will strip electrons from other atoms or temporarily pull them into a higher energy shell. An alpha particle comes from a heavy nucleus that does not have enough neutrons (the n:p ratio is too low). It is represented by either of the following:

$$^{4}_{2}\alpha \text{ or } ^{4}_{2}He$$

When a nucleus emits an alpha particle, its atomic number is decreased by two and its mass number by four; therefore, it must become a different nuclide. For example, the parent nuclide radium (Ra)–226 (a member of a naturally-occurring radioactive family or decay series) decays by alpha emission to the daughter nuclide, radon (Rn)–222. Rn–222 is still an unstable atom; consequently, it too becomes a parent and emits an alpha particle producing the daughter nuclide, polonium (Po)–218. This transmutation process is illustrated in the following equation:

$$^{226}_{88}Ra \rightarrow \, ^{222}_{86}Rn + \, ^{4}_{2}\alpha \rightarrow \, ^{218}_{84}Po + \, ^{4}_{2}\alpha$$

Note that Ra–226 loses four mass (m) units and two protons to produce a daughter with a mass number of 222 and an atomic number of 86. The parent numbers on the left must equal the combined numbers of the daughter and alpha on the right. This makes it easy to determine what the daughter will be by simply matching the atomic number to the proper element in the periodic table of elements.

Immediately after an alpha particle is formed, it shoots out of the nucleus with a kinetic energy (corresponding to a certain velocity) that depends upon the decrease in mass of the parent atom as compared to the leftover parts. That is, there is missing mass that shows up as the kinetic energy of the alpha particle. The total mass of the parent must equal the sum of the masses of the daughter, the alpha, and two electrons (the electron mass is not significant) which are liberated in forming the daughter, and the mass that was converted to the energy of decay as in the following:

Parent mass = daughter mass + alpha mass + 2 electron masses + mass for energy.

Figure 1–1 illustrates how alpha emission works:

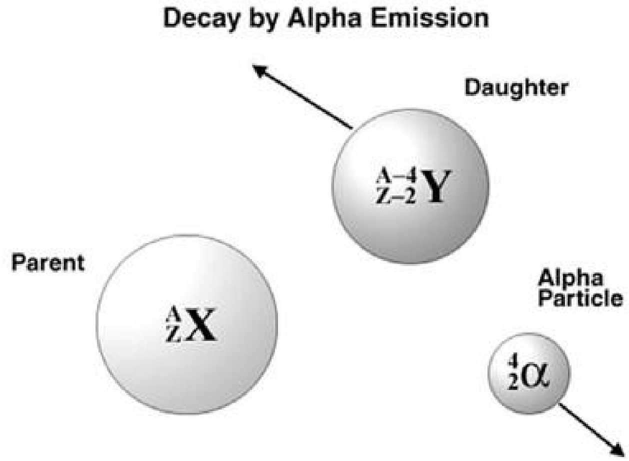


Figure 1–1. Decay by alpha emission.

Most alpha emitters produce an alpha of the same energy for every transformation, but a few will occasionally emit one of lower energy. For example, 95 percent (%) of the Ra–226 transformations produce an alpha with 4.78 megaelectron-volts (MeV), while 5% result in an alpha with 4.59 MeV. The reason for this is that some of the energy that would otherwise have gone to the alpha is instead transmitted to the nucleus, leaving the daughter nuclide in an excited state. The nucleus throws out this "excess" energy in the form of a gamma ray to reach ground state. The difference in energy between the two alpha particles gives the energy of the gamma 0.186 MeV (fig. 1–2). The gamma emission usually happens instantly, but sometimes the excited state of the daughter is *metastable*, meaning that the gamma ray may not be emitted for some time.

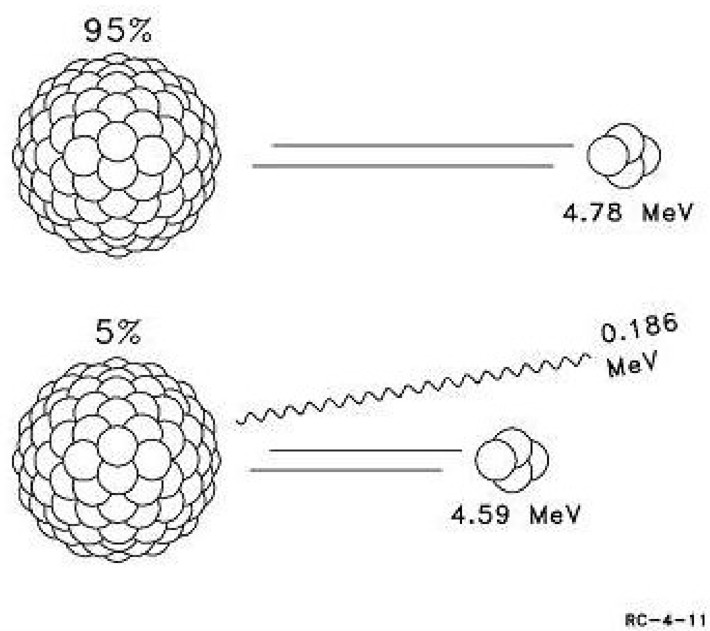


Figure 1–2. Ra–226 decay to Rn 222.

In some cases, the gamma ray (accompanying the alpha particles emitted) does not make it through the electron cloud. In this process, called internal conversion, the nucleus rids itself of the excess energy and an electron around the nucleus absorbs the energy, resulting in the electron being ejected from the atom. This ejected electron must be replaced by an electron from a higher orbit. Figure 1–3 illustrates how this may occur. The electron in the higher shell has more energy (revolves around the nucleus faster) than the original electron; consequently, it throws off the "excess" energy in the form of a radiography (X-ray) when it fills the lower gap. Each vacancy must be replaced, in turn, by an electron from a higher orbit (shell), resulting in a "cascade of electrons" and a number of photons of varying energy.

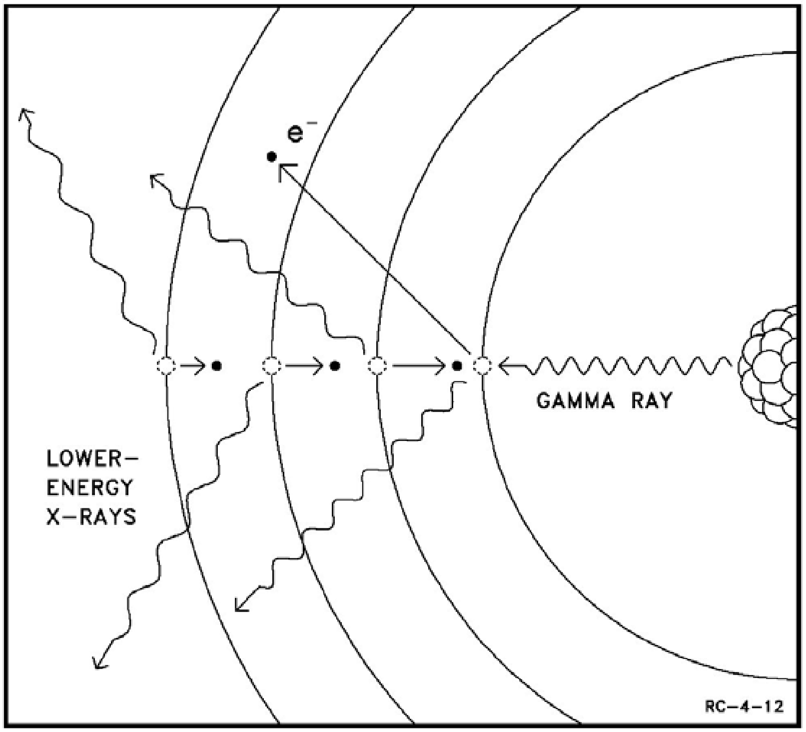


Figure 1–3. Internal conversion.

Each electron emits an X-ray photon corresponding to the difference in energy between the higher energy shell and the newly filled shell. The X-rays are called *characteristic X-rays* because their energies are characteristic of the energy differences between the electron shells of the atoms from which they came. The process occurs even more often in beta radiation.

Beta decay

Similar to alpha decay, beta (β) decay is a process that unstable atoms use to become more stable. The two types of β-decay include beta minus decay and beta plus decay.

Beta minus

During beta minus (β^-) decay), a neutron in an atom's nucleus turns into a proton, an electron, and an antineutrino (neutral particles that rarely interact with matter). The electron and antineutrino fly away from the nucleus, which now has one more proton than it started with, changing the element from one to another. A beta particle (sometimes called a *negatron*) is identical in mass and charge (–1) to an electron. Since it is much lighter and faster than an alpha particle, it travels farther, but has less ionizing ability. β decay occurs in both light and heavy nuclei with n:p ratios that are too high (an excess of neutrons), and this requires the nuclide to rid itself of the excess neutrons. Figure 1–4 illustrates this process in which a neutron in the parent nucleus converts to a proton and a beta, and the beta is ejected. This transmutation produces a daughter nuclide with an atomic number of one more than the parent and has the same mass due to the negligible mass of the beta that is lost. The actual mass of the daughter is slightly lower, but it still rounds off to the same mass number as the parent.

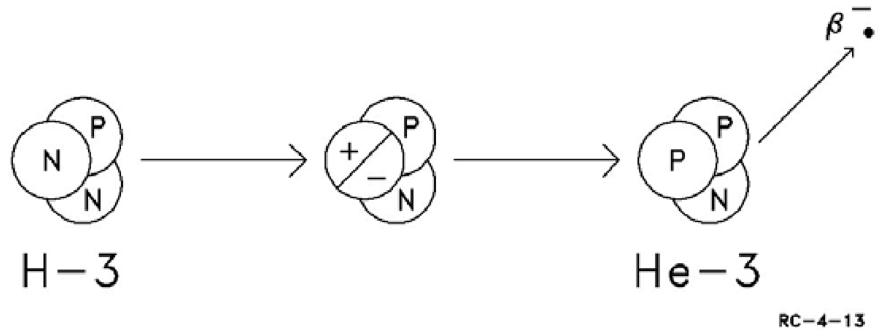


Figure 1–4. Beta decay.

Refer to the example of alpha decay covered earlier, in which Ra–226 ended with Po–218, which can decay by either alpha or beta emission. It will emit alpha in about 99.98% of its transformations and beta in the remaining 0.02%. Interestingly, Po–218 undergoing alpha decay produces lead (Pb)–214, which then decays by beta to Bi–214, while Po–218 undergoing β-decay first produces astatine (At)–218, and then decays by alpha and also becomes Bi–214.

99.98%:

$^{218}_{84}Po \rightarrow \, ^{214}_{82}Pb + \, ^{4}_{2}\alpha \rightarrow \, ^{214}_{83}Bi + \, ^{0}_{-1}\beta$

0.02%:

$^{218}_{84}Po \rightarrow \, ^{218}_{85}At + \, ^{0}_{-1}\beta \rightarrow \, ^{214}_{83}Bi + \, ^{4}_{2}\alpha$

Similar to alpha decay, the kinetic energy—and thus the range and penetrating ability—of beta is dependent upon the difference between the mass of the parent and that of the daughter (plus some other considerations). The loss of the beta mass is balanced by an electron that must be immediately captured because of the extra positive charge produced by the new proton.

Beta plus

During beta plus (β^+) decay, a proton in an atom's nucleus turns into a neutron, a positron (positively charged beta particle and thus is somewhat of a "mirror image" or antimatter counterpart of beta) and a neutrino. The effects on a nuclide emitting this radiation are just the opposite of beta (negatron) decay. In beta plus decay, sometimes referred to as positron, the parent nucleus changes a proton into a neutron and gives off a positively charged particle. A proton is converted to a neutron and a positron; resulting in a daughter nuclide with an atomic number that is 1 lower than the parent and the mass number remains the same. Since an atom loses a proton, it changes from one element to another. Sodium (Na)–22 helps to illustrate this formula:

$$^{22}_{11}Na \rightarrow \, ^{22}_{10}Rn + \, ^{0}_{1}\beta$$

Electron capture decay

For nuclides having a low n:p ratio, another mode of decay known as EC can occur. Additionally known as K-capture, EC occurs when a nucleus with too few neutrons captures an orbital electron, usually from the K-shell (the innermost orbit) since the electrons in that shell are closest to the nucleus. Occasionally, the EC will occur from the L-shell (the second orbit). The captured electron unites with a nuclear proton to form a neutron, resulting in an increase of neutron number by one and a decrease of proton number by one. This transmutation may leave the daughter nucleus in an excited state, in which case the daughter nucleus will emit a gamma ray (characteristic of that excited state).

In EC transformations, the electron combines with a proton to form a neutron, followed by the emission of a neutrino. Electrons from higher energy levels immediately move in to fill the vacancies left in the inner, lower-energy shells. The excess energy emitted in these moves results in a cascade of characteristic X-ray photons which will be discussed further in the section on X-ray production.

This process results in effects very similar to those seen with positron emission (PE) and is often found as an alternate to positron decay in many nuclides. Na–22, for instance, undergoes positron decay for 90.6% of its transformations and EC for the remaining 9.4%. Figure 1–5 shows the difference in the two decay processes.

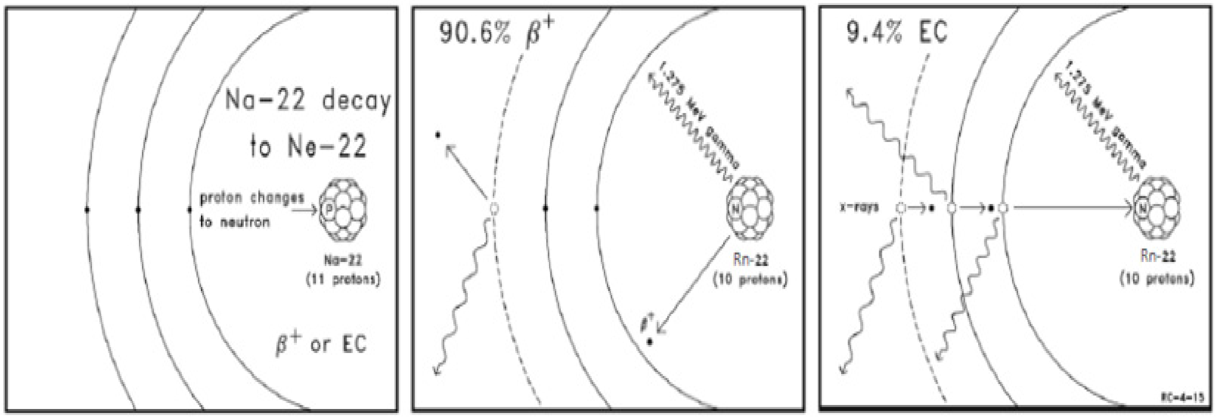


Figure 1–5. Positron and E-C decay.

The radiation emitted is the same (1.275 MeV gamma) from the excited daughter nucleus regardless of whether the transformation is a result of positron decay or EC.

Isomeric transition

All the transmutation examples previously discussed could be accompanied by gamma emission. Usually, the gamma is emitted promptly after transmutation; in other cases, the gamma emission is slightly delayed. The transmuted nucleus remains in an excited state for a measurable amount of time before finally emitting a gamma ray; this is known as *isomeric transition*. The difference between isomeric transition and other gamma emissions is the relatively long excited state of the daughter nucleus during isomeric transition.

A nucleus that remains in such an excited state is known as an *isomer* because it is in a “meta-stable state.” This means the nucleus differs in energy and behavior from other nuclei with the same atomic and mass number. Generally, the isomer achieves ground state by emitting delayed gamma radiation. This excited state is usually represented by a small “mass” following the mass number in the standard nuclide notation.

Neutrons

There is no specific process in which an isotope is said to undergo neutron decay, but neutrons make up an important type of radiation usually produced by certain artificial reactions. Most methods of producing neutrons involve bombarding a suitable nuclide with charged particles (such as alpha), other neutrons, or high-energy gamma rays to make the target nuclide give up a neutron. Fission is another significant source. Free neutrons are radioactive entities in themselves and will disintegrate in free space to form a proton and beta particle within a few minutes. In matter (including air), they are captured by nuclei before they can decay. Although a neutron has no charge, its methods of interacting with matter make it quite hazardous to body tissues. The type of interaction depends heavily on the kinetic energy (speed) of the neutron, so this energy is used to classify them. At ordinary room temperatures, the most probable velocity of free neutrons is about 220,000 centimeters per second (cm/sec), or 7218 feet per second (ft)/sec, which corresponds to a kinetic energy of 0.025 electron volt (eV). Neutrons of this energy are called *thermal neutrons* and are the slowest neutrons.

Fission

Most people recognize *fission*, which is the splitting of a nucleus into at least two other nuclei that releases a large amount of energy, as the term associated with nuclear reactors and/or bombs. However, there is also a natural mode of decay called *spontaneous fission* in which nuclei fall apart on their own. The most common of such nuclides is Californium–252, which is a very strong neutron emitter produced artificially in nuclear reactors and particle accelerators. Most fissionable nuclides are alpha emitters, but many will undergo spontaneous fission instead of alpha decay for a small percentage of their transformations. Common among the very heavy nuclei needed for "fissioning" are U–235 and Pu–239. When such nuclides experience fission, additional neutrons are released, small amounts of mass are converted to great amounts of energy, and many different isotopes are formed. Most of the newly formed isotopes are radioactive and emit a mixture of alpha, beta, and gamma/X-ray radiation.

The n:p ratio and the energy available will determine the way in which an unstable nucleus will decay.

Common isotopes and types of decay

Ionizing radiation sources are common to many Air Force (AF) operations, used in medical diagnostics and therapy; non-destructive inspection (NDI) of aircraft parts and baggage, security forces, AF research operations, electronics systems vulnerability testing, hazardous compound testing, and others. The sources fit into one of two categories: radioactive material (RAM) and machine-generated (e.g. X-rays). From a practical standpoint, radiation protection management is very similar for both sources. The primary differences in management reside in different regulatory entities and the requirement RAM being controlled during non-use periods and has long-term management responsibility for long-lived isotopes.

Photon Emissions and Radioactive Decay Mode for RAM in AF Operations

Radioisotope Half-life ($t_{1/2}$)	Decay Mode	Significant Photon Emission Energy in kiloelectron-volts (keV), Frequency, and Type	Use
F–18 ($t_{1/2}$: 110 min)	Positron (97%) Electron Capture (3%)	511 (194%) – γ (gamma) oxygen X-rays	Nuclear Medicine
Na–24 ($t_{1/2}$: 15 h)	Beta	1.369 (100%) – γ 2.754 (100%) – γ	Neutron Activation Product of Na–23
Fe–55 ($t_{1/2}$: 2.7 y)	Electron Capture	manganese X-rays	X-ray Fluorescence Devices
Co–57 ($t_{1/2}$: 272 days)	Electron Capture	122 (87%) – γ 136 (11%) – γ iron X-rays	X-ray Fluorescence, Some Generally-Licensed devices
Co–60 ($t_{1/2}$: 5.3 y)	Beta	1,173 (100%) – γ 1,332 (100%) - γ	Check sources, irradiators, industrial radiography.
Ga–67 ($t_{1/2}$: 3.3 days)	Electron Capture	93 (40%) – γ 184 (24%) – γ 296 (22%) – γ 388 (7%) – γ	Nuclear medicine.
Kr–85 ($t_{1/2}$: 10.8 y)	Beta	514 (0.41%) – γ	Check sources, gauges, exciter circuits.
Mo–99 ($t_{1/2}$: 66 h)	Beta	181 (7%) – γ 740 (12%) – γ 780 (4%) – γ	Nuclear Medicine

Photon Emissions and Radioactive Decay Mode for RAM in AF Operations			
Radioisotope Half-life ($t_{1/2}$)	**Decay Mode**	**Significant Photon Emission Energy in kiloelectron-volts (keV), Frequency, and Type**	**Use**
Tc–99m ($t_{1/2}$: 6 h)	Internal Transition	140 (90%) – γ technetium X-rays	Nuclear Medicine
Pd–103 ($t_{1/2}$: 17 days)	Electron Capture	rhodium X-rays	Nuclear Medicine
Cd–109 ($t_{1/2}$: 1.26 y)	Electron Capture	88 (12%) – γ silver X-rays	X-ray Fluorescence, Lead-Based Paint Analyzers
In–111 ($t_{1/2}$: 2.8 days)	Electron Capture	173 (89%) – γ 247 (94%) – γ	Nuclear Medicine
I–123 ($t_{1/2}$: 13 h)	Electron Capture	159 (83%) – γ	Nuclear Medicine
I–125 ($t_{1/2}$: 59.4 days)	Electron Capture	35 (7%) – γ tellurium X-rays	Nuclear Medicine
I–131 ($t_{1/2}$: 8 days)	Beta	284 (5%) – γ 364 (82%) – γ 637 (7%) – γ	Nuclear Medicine
Xe–133 ($t_{1/2}$: 5.2 days)	Beta	81 (37%) – γ	Nuclear Medicine
Cesium–137 (Cs–137) (t1/2: 30 y)	Beta	662 (85%) – γ barium X-rays	Check Sources, Industrial Radiography, Calibration, Exciter Circuits, Irradiators
Ir–192 (t1/2: 74 days)	Beta (95.5 %) Electron Capture (4.5 %)	296 (29%) – γ 308 (30%) – γ 317 (81%) – γ 468 (49%) – γ 589 (4%) – γ 604 (9%) – γ 612 (6%) – γ	Industrial Radiography
Tl–201 (t1/2: 73 h)	Electron Capture	135 (2%) - γ 167 (8%) - γ mercury X-rays	Nuclear Medicine
Ra–226 (t1/2: 1600 y)	Alpha	186 (4%) – γ radon X-rays photons from daughters: Rn–222, Po–218, Pb–214, Bi–214, Po–214	Luminous Products, Neutron Sources (with (w/) Beryllium [Be])
Th–230 (t1/2: 7.5 x 104 y)	Alpha	68 (0.4%) - γ radium X-rays	Check Sources
Th–232 (t1/2: 1.4 x 1010 y)	Alpha	radium X-rays photons from daughters: Ra–228, Ac–228, Th–228, Ra–224, Rn–220, Po–216, Pb–212, Bi–212, Tl–208	Magnesium-Thorium Alloy (Aircraft Engine Parts, Missile Skins), Thoriated Glass Coatings, Check Sources
U–234	Alpha	thorium X-rays	30 mm Ammunition, Nuclear

Photon Emissions and Radioactive Decay Mode for RAM in AF Operations			
Radioisotope Half-life ($t_{1/2}$)	**Decay Mode**	**Significant Photon Emission Energy in kiloelectron-volts (keV), Frequency, and Type**	**Use**
(t1/2: 2.5 x 105 y)			weapons, Counterweights
U–235 (t1/2: 7.0 x 108 y)	Alpha	143 (11%) – γ 185 (57%) – γ thorium X-rays	30 mm Ammunition, Nuclear weapons, Counterweights, Calibration
U–238 (t1/2: 4.5 x 109 y)	Alpha	thorium X-rays photons from daughters: Th–234, Pa–234m	30 mm Ammunition, Nuclear weapons, Counterweights
Pu–238 (t1/2: 88 y)	Alpha	uranium X-rays	Radioisotope Thermoelectric Generators
Pu–239 (t1/2: 2.4 x 104 y)	Alpha	uranium X-rays	Nuclear weapons, Neutron Sources (w/ Be), Calibration
Am–241 (t1/2: 432 y)	Alpha	60 (36%) - γ neptunium X-rays	Static Eliminators, Chemical Agent Detectors, Neutron Sources (w/ Be)

RAM in AF Operations Without Photon Emissions			
Radioisotope (Half-life)	**Decay Mode**	**Particle Energy (keV)**	**Use**
H–3 ($t_{1/2}$: 12.3 y)	Beta	19 (maximum)	Exit Signs, Biological Research, Nuclear weapons, Luminous Products
C–14 ($t_{1/2}$: 5730 y)	Beta	156 (maximum)	Astroinertial Navigation Devices, Biological Research
P–32 ($t_{1/2}$: 14.3 days)	Beta	1,710 (maximum)	Biological Research
Ni–63 ($t_{1/2}$: 100 y)	Beta	66 (maximum)	Ionscans, Chemical Agent Monitors/Alarms, Gas Chromatographs
Sr–90/Y–90 ($t_{1/2}$: 29 y)	Beta	546/2,270 (maximum)	In-flight Blade Inspection Systems (IBIS), Ice Detectors, Radioisotope Thermoelectric Generators, Calibration
Pm–147 ($t_{1/2}$: 2.6 y)	Beta	224 (maximum)	Luminous Products, Electron Tubes
Re–187 ($t_{1/2}$: 4.4 x 10^{10} y)	Beta	3 (maximum)	Electron Tubes
Po–210 ($t_{1/2}$: 138 days)	Alpha	5,305	Static Eliminators, Calibration, Neutron Sources

623. How radiation interacts with matter

Absorption of radiation is the process of transferring energy from the radiation to the matter with which it interacts (passes through). It starts with a collision between an ionizing particle (or photon) and some part of an atom in its path. In this context, a collision does not necessarily mean that the ionizing particle must come into actual contact with the subatomic particle; rather, that it passes sufficiently close to affect it in some way. For example, alphas, betas, positrons, and other charged particles may pass close enough to an atom to interact with its electrical field (where there is either an attraction or repulsion) and there is a loss of some of the particle's energy. Charged particles are said to be *directly ionizing* for this reason. Gamma, X-ray, and neutrons are *indirectly ionizing* because they have no electrical charge to play a part in their interactions. Radiation interactions are of concern not only because of the potential damage to body tissues; they also provide a basis for detection methods and determining shielding.

Some radiations have mass (alphas, betas, and neutrons), and some do not (gamma rays and X-rays). Some radiations are charged (alphas and betas), while others are not (gamma rays, X-rays, and neutrons). It is important to gain an understanding of how the various properties of radiation determine how they will interact with matter. An understanding of how radiation interacts with matter is fundamental to understanding the following:

- How radiation is detected with an instrument.
- How a radiation dose is delivered to human tissue.
- What makes an effective protective shield.
- What radiation protection techniques will be effective.

Charged Particles

There are over a dozen ways in which charged particles interact and deposit energy in matter; however, the following are three major mechanisms that account for most all energy deposited:

1. Ionization.
2. Excitation.
3. Bremsstrahlung.

Ionization

The ionization process involves complete removal of orbital electrons, as shown in figure 1–6. This process removes the charge from a neutral atom, creating highly reactive ions (atoms or molecules that have an electric charge). The combination of the removed electron (-) and the rest of the atom (+) is called an ion pair.

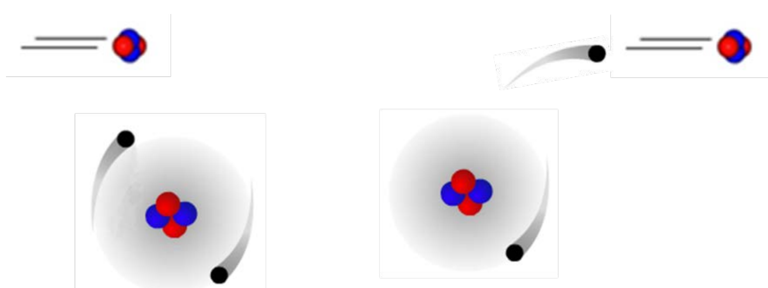


Figure 1–6. Ionization.

Excitation

In contrast to ionization, the excitation process involves not having sufficient energy to remove the electron. Rather than leaving the atom completely, the electron merely jumps to a higher atomic energy level, ordinarily from the condition of lowest energy (ground state) to one of higher energy (excited state), as shown in figure 1–7.

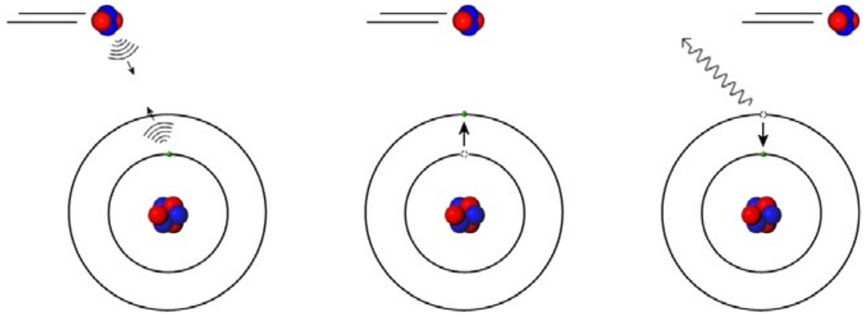


Figure 1–7. Excitation.

Bremsstrahlung

The last of the three major atomic processes of energy removal is named *bremsstrahlung*, which is of German origin, meaning "braking radiation." With bremsstrahlung, radiation is generated when a relatively fast-moving particle nears a nucleus and the attractive force alters its trajectory, causing it to slow down (fig. 1–8). This change in direction is, in the physics sense, a negative acceleration (a deceleration); the velocity vector changes with the directional change and the speed of the particle is reduced due to the loss of energy. The radiation emitted by the particle, in the form of a photon, is electromagnetic in nature, usually in the X-ray region of the electromagnetic spectrum. The amount of energy lost, and thus the energy of the photon, depends upon how closely the electron passes to the nucleus. This interaction is particularly true of negative betas and is also true of electrons as they pass through matter.

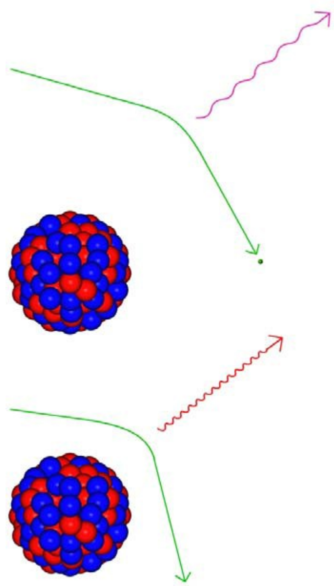


Figure 1–8. Bremsstrahlung production.

Generally, all three processes (ionization, excitation and bremsstrahlung) occur simultaneously as a beam of charged particles passes through matter. In the case of human tissue as the absorber, ionization and excitation account for about 99% of the energy deposited, while bremsstrahlung accounts for the remaining 1% of energy.

As each charged particle travels, it will lose a small amount of its energy to each atom along its path in a process called *linear energy transfer* (LET). As energy is transferred, the electrons become excited or gain enough kinetic energy to escape the atom, yet tend to pull back slightly on the particle. This causes the particle to lose energy and slow down until it is eventually captured to form a non-ionized atom.

Alpha particle interactions

Alpha particles are the least penetrating of the radiations. In air, even the most energetic alphas from radioactive substances travel only several centimeters. In tissue, the range of alpha radiation is measured in microns. The major energy-loss mechanisms for alpha particles considered significant in health physics are collisions with the electrons in the absorbing medium. These interactions result in electronic excitation and ionization of the absorber atoms. The fact that alpha particles are the least penetrating does *not* mean they are harmless. As a matter of fact, the effects are quite the opposite. The double positive charge (+2) of the alpha particles indicates they are intensely ionizing. They are emitted from the nucleus with a lot of energy and they lose that energy very rapidly. The specific ionization of an alpha particle is very high, on the order of tens of thousands of ion pairs per cm in air. In comparison, betas only produce about 45 ion pairs per cm. As the mass of the alpha is over 8,000 times that of the electron, and its energy is generally on the order of 1 to 10 MeV, it can affect a very large number of electrons while maintaining a straight (although short) path in the medium. However, the other types of radiation follow a more tortuous path as they are deflected, or scattered, in many different directions.

High alpha particle ionization results from its high electrical charge and relatively slow speed due to its great mass. The slow speed allows a long interaction time between the electric fields of the alpha particle and an orbital electron of an atom in the medium through which the alpha particle passes. This allows sufficient energy to transfer and ionize the atom with which it collides. As the alpha particle undergoes successive collisions and slows down, its specific ionization increases because the electric fields of the alpha particle and the electron have longer times to interact. Consequently, more energy can be transferred per collision. This increasing ionization density leads to a maximum specific ionization near the end of the alpha particle’s range, as shown in figure 1–9. This maximum is called the *Bragg peak*, after the British physicist Sir William Henry Bragg, who studied radioactivity during the early 1900s. An alpha particle loses energy at an increasing rate, slowing down until the *Bragg peak* is reached near the end of its range.

As previously mentioned, the more it slows, the longer it remains in a given area, resulting in the increased probability of ionization. The amount of energy required to ionize a molecule of air averages 33.7 eV. The alpha loses about 35 eV per ion pair; the number of ion pairs formed along the path of one alpha can be calculated according to its beginning energy. For example, a 1 MeV alpha can produce 28,571 ion pairs, as shown in the following equation:

$$Total\ ion\ pairs = \frac{1{,}000{,}000\ eV}{35\ ev/_{ion\ pair}} = 28{,}571\ ion\ pairs$$

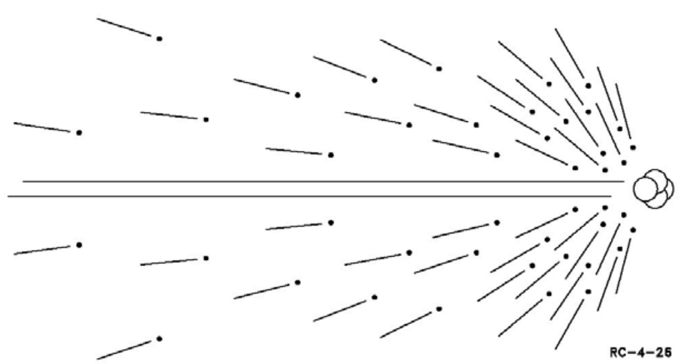


Figure 1–9. Linear energy transfer.

It is useful when comparing different types of radiation to state the average number of ion pairs formed per each cm of travel. This *specific ionization* is found simply by dividing the total ionizations (ion pairs) by the range of the alpha in the matter of interest (usually air, for the sake of comparisons). Thus, a 1 MeV alpha above a 0.56-cm range has the specific ionization shown in the following equation:

$$Specific\ ionization = \frac{28{,}571\ ion\ pairs}{0.56\ cm} = 51{,}020\ ion\ pairs\ /\ cm$$

In the preceding example, the 1 MeV alpha particle gives the indication that all alpha particles have very short ranges. The exact range depends not only upon the kinetic energy of the particle, but also on the density of the medium it passes through. Even an 8 MeV alpha has a range of only 7.3 cm (2.87 inches) in air; therefore, the shielding against alpha is not much of a problem. Most alpha cannot even pass through paper or skin. It takes at least 7.5 MeV to penetrate the protective layer of skin; therefore, when the skin is penetrated, there is still insufficient energy to do much damage. On the other hand, alpha traveling through very rarefied gas can still travel considerably further before it finds matter to interact with and eventually stop. In a perfect vacuum, its range would be unlimited. The danger comes when an alpha-emitting isotope gets inside the body through inhalation; this allows the radiation to do significant damage to the soft unprotected cells it encounters.

Beta particle interactions

The beta particle has a lower probability of interaction than the alpha due to its smaller mass and higher speed; therefore, it has a much lower LET. These attributes make the beta particle less likely than alpha to suffer a “collision” along a given length of path; therefore, it travels greater distances between collisions. The beta particle causes *excitation* and *ionization* by the force of repulsion between itself and the orbital electrons. It may lose all its energy in a single collision, making the target electron a secondary ionizing particle. However, it will far more often interact with a large number of atoms and gradually dissipate its energy similar to alpha. Since it has so little mass, it is easily deflected and each collision is likely to send it in another direction, giving it quite a crooked path (fig. 1–10).

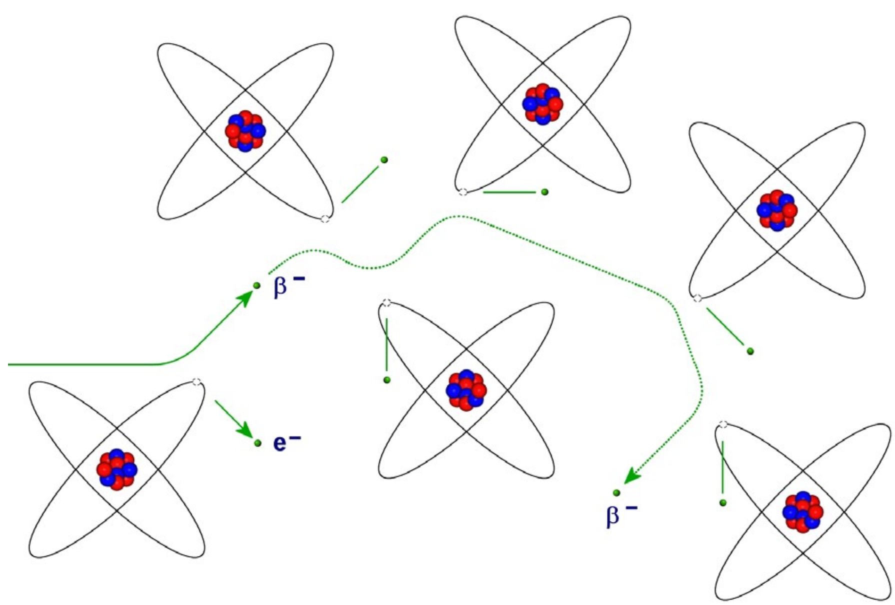


Figure 1–10. Path of a beta particle.

A beta particle loses about 33.7 eV for each ion pair it creates in air. It therefore produces about the same number of ion pairs as an alpha of the same energy, but its specific ionization is lower. A 1 MeV beta can produce up to 29,674 ion pairs in air, but its specific ionization is only about 86.5 ion pairs/cm. Contrast this with the more heavily ionizing 1 MeV alpha, which produces 51,020 ion pairs/cm. This means betas travel further through matter before losing all their energy, as previously mentioned. Depending on the isotope, maximum energies can be anywhere from about 0.01 to 10 MeV and higher, corresponding to ranges in air of 0.13 cm (0.05 inches) to over 4,328 cm (142 ft). The beta energies from most isotopes, however, are considerably below 10 MeV (more in line with the 1 MeV beta, which has a range of 343 cm, or 11 ft, in air).

Ionization will occur in the atoms adjacent to the beta particle's trajectory. Atoms that are located further away from this trajectory may still experience the force of repulsion or attraction as the beta passes. The force may not be large enough to ionize these atoms, but they may become *excited*. Similar to atoms excited by alphas, atoms excited by betas will subsequently de-excite by emitting low energy photons, typically in the ultraviolet range. Beta particle tracks are long and tortuous; the range of beta particles is typically much shorter than their track length. Calculating the beta range will be useful when evaluating hazards from beta particles or evaluating shielding designs.

Although beta is generally thought to interact with orbital electrons, high-energy betas can penetrate the electron cloud and be affected by the attractive force of the nucleus (bremsstrahlung). Bremsstrahlung is the principle used in X-ray machines, although electrons are used to bombard material rather than beta. Most of these interactions result in heat radiation, but a few of them produce X-rays. To avoid bremsstrahlung production for purposes of radiation safety protection, the betas must be surrounded by low atomic number material, such as plastic. This concept is applied in the construction of shielding around high-energy beta sources.

Positron interactions

Positron interactions are similar to those of beta as far as masses, energies, and specific ionizations are concerned. The difference lies in the mechanisms of *excitation* and *ionization*; there exists a force of attraction between positrons and orbital electrons rather than repulsion. The most significant difference with positron radiation is the phenomenon known as *annihilation radiation*. After many interactions have taken most of the energy of a positron, slowing it down sufficiently, its final encounter with an electron causes the destruction of both particles. In this "annihilation," the masses of both particles are converted to 2 gamma rays. The mass of each particle, 0.000549 atomic mass unit (amu), produces a gamma ray of 0.511 MeV. Figure 1–11 illustrates positron interactions.

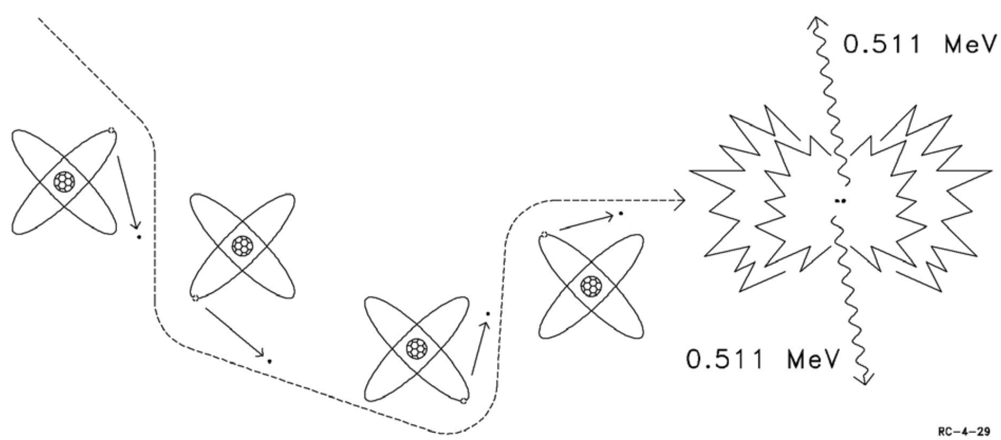


Figure 1–11. Annihilation radiation.

Gamma/X-ray interactions

Having no mass, no charge, and traveling at the speed of light (c), gamma and X-ray photons can pass through considerable amounts of matter before interacting with it. That is, the probability of interaction is quite low compared to charged particles. However, this radiation is a very serious external hazard due to its high penetrating ability. Skin does not protect against it, as it does against alpha, beta, and positron radiation. The interactions are discussed in the following paragraphs in the order of increasing photon energy involvement. Refer to figure 1–12 to help clarify these concepts.

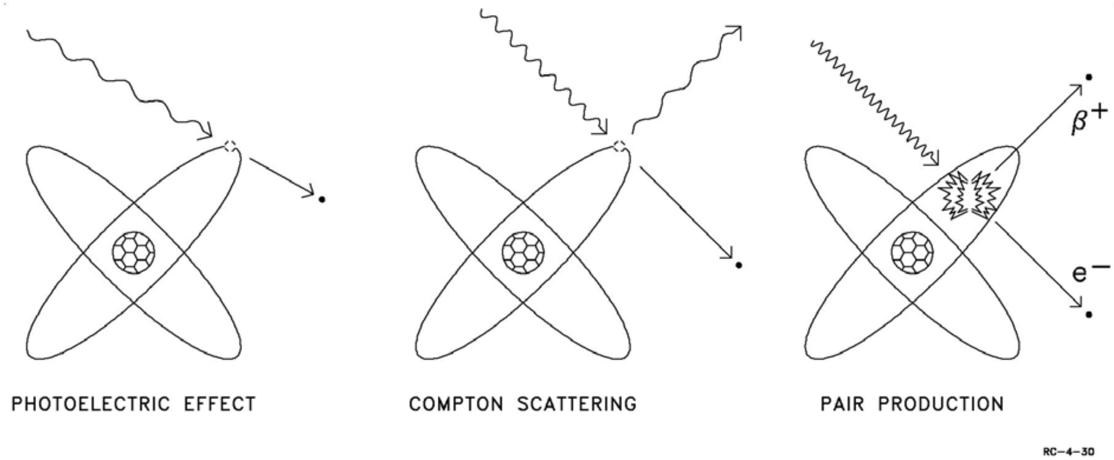


Figure 1–12. Gamma/ X-ray interactions.

Photoelectric effect

Photons of very low energy cannot significantly affect the atoms of the matter they pass through; they are simply scattered in different directions until they are completely absorbed and produce mild excitation effects (such as heat or fluorescence). Photons of higher (but still fairly low energy) are able to produce ionizations by *photoelectric effect*. This involves a collision with an electron, usually in the K or L shell, in which the photon gives up all its energy in removing the electron from the atom. The photon must have the energy at least equal to the binding energy of the electron it removes. Any excess energy is imparted to the electron, now called a photoelectron, as kinetic energy that is dissipated by further ionizations and excitations. Not all photons of a given energy will interact in this way. Many will cause various types of excitation, while some will interact by the photoelectric effect. The effect becomes more and more probable (more atoms are ionized and fewer excited) as photon energy increases. In water (H_2O) and body tissues, the photoelectric effect is important, with photon energies up to roughly 0.03 MeV (30 keV).

Compton scattering

Above 30 keV, the photoelectric effect still occurs, but *Compton scattering* begins to take over as the dominant gamma/X-ray interaction. This takes place between a photon and an outer electron (outer electrons have far less binding energy than inner electrons). The photon has more energy than the electron can accept, so it imparts only a portion of its energy to the electron. The electron (Compton electron) flies free at great speed (approaching the speed of light) and becomes a secondary ionizing particle. The weakened photon travels off in another direction, losing energy in additional Compton scattering and/or disappears completely by the photoelectric effect or excitation. The amount of energy transferred depends upon the angle of the photon's scatter compared to its original path. The angle of scatter depends upon the angle at which the photon hits the electron. As illustrated in figure 5–12, a "grazing" hit will produce a very small angle of scatter and little energy is transferred. A "head-on" hit will result in the maximum scatter angle of 180º along with the maximum energy transfer (all the energy the electron can take).

Pair production

This interaction is much rarer than the previous interactions; it requires a photon of at least 1.022 MeV. It does not become important until photons of at least 2 MeV are involved and does not predominate unless energies are much higher. In pair production, a photon disappears in the vicinity of a nucleus and an electron and positron appear in its place (the opposite of the positron interaction). Any energy left over from their formation is shared by the particles as kinetic energy. Both particles fly out from the atom and produce secondary ionizations until their energy is almost gone. The electron is eventually captured, but the positron is attracted by another electron in the medium, and the two are *annihilated*. This results in a pair of gamma rays (0.511 MeV each). These gamma rays also enter into photoelectric, Compton, and other interactions until they disappear. Note that there is no clear-cut point at which one type of effect ends and another begins. There is often a variety of different interactions occurring simultaneously, all caused by the same radiation.

Neutrons

Just as the n's absence of charge enables it to leave an atom more easily than can a charged particle, the neutron can also penetrate the atom more easily. The measure of probability that a "specified interaction" will occur between a particle and a nucleus or other particle is termed the *cross section*. It is usually the effective area that a nucleus presents to the particle under a certain set of conditions. For example, a nitrogen–14 nucleus presents a high cross section to a low-energy neutron for a certain effect. There is a high probability that the effect will take place. The cross section for the same nucleus and effect is very low for fast neutrons; therefore, the effect has a low probability. A rough analogy would be shooting at a target with a scope first and then secondly, without the scope. It is easy to determine which situation allows for the higher probability of hitting the target or in which case the target has a larger effective area. Cross sections are used for other types of radiation as well but are most often used when speaking of "neutron effects." These effects are quite different from any of those discussed thus far. All neutrons are fast when they are first emitted but lose energy in numerous collisions until they become slow or "thermal neutrons" and are captured. Slow neutrons are more likely to be detected.

Scatter

Fast neutrons with energies roughly between 1 and 10 MeV undergo what is called "inelastic scatter" (fig. 1–13). They gradually lose kinetic energy in a series of collisions, primarily with heavier nuclei. The neutron is either captured or immediately re-emitted by the nucleus (or possibly a different neutron is emitted), or it bounces off the nucleus. Either way, the neutron imparts some of its energy to the nucleus and is, therefore, slowed down and scattered in another direction. The nucleus, in an excited state after the encounter, rids itself of the excess energy by emitting a gamma ray. This effect is known as the *photoneutron effect*, which signifies an incoming neutron as the initiator and the outgoing gamma ray as the product.

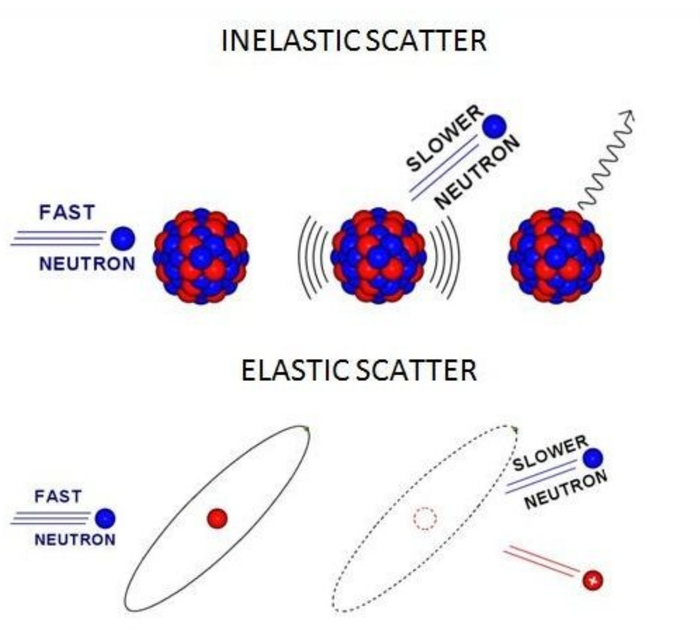


Figure 1–13. Neutron scatter interactions.

Also shown in figure 1–13, fast neutrons below 1 MeV down to about 0.01 MeV undergo so-called "elastic scatter," in which nuclei do not receive excitation energy. Affecting mainly light nuclei, such as hydrogen and oxygen, this interaction is often compared to two billiard balls. The neutron hits the nucleus and sends it flying off from its electrons. The recoil nucleus with its strong positive charge, especially in the case of an oxygen ion, becomes a very heavily ionizing particle, while the neutron slows and scatters in a different direction to proceed with other interactions. This process can cause significant damage to body tissues given that the body contains primarily H_2O (hydrogen and oxygen). The slowing, or *moderating*, of fast neutrons enables them to be captured more easily; meaning the absorption cross-section of a particular nucleus is increased.

Capture

Depending upon the neutron energy and type of nucleus, several things may happen when a neutron is captured (fig. 1–14). Typically, neutrons capture results in an isotope with an atomic weight of one higher than the original target and the emission of a gamma ray (i.e., iodine–127 capturing a neutron to form iodine–128). The notation is the same as seen with inelastic scatter (n, γ) but the neutron is not reemitted. Capture of slow neutrons by heavier nuclei with the emission of gamma is the most common, because charged particles require higher energies to remove them from most atoms. Capture is one of the principle means of artificially producing isotopes. In addition to neutrons, several other particles, such as protons and alpha, are used to bombard various isotopes to produce others.

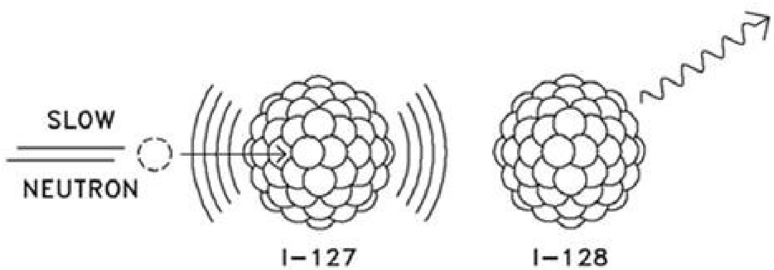


Figure 1–14. Neutron capture interactions.

Fission

With a few isotopes, the capture of a neutron causes fission, or the splitting of a nucleus. Isotopes such as U–235 and Pu–239 are called *fissile materials* as they can easily be fissioned by thermal (slow) neutrons, which is to say that they have high fission cross sections. Materials such as U–238 and Th–232 are also fissionable but not fissile, because they can only be fissioned by fast neutrons, and not very efficiently. Using U–235 as an example, capture first results in a compound nucleus (U–236 in this case) which is very unstable due to the energy released by the neutron capture. The nucleus then splits into two radioactive fission fragments. There are about 40 different ways the nuclei can split, yielding a possible 80 initial fission fragments ranging from a mass number of 30 to 158. As these fragments decay (along with their descendants), there is very soon a complex mixture of more than 300 different isotopes, many of which are useful byproducts. Most of these have excesses of ns, which cause them to decay primarily by beta emission.

To obtain the desired effects (also sometimes the undesired effects) from fission, a self-sustaining chain reaction is needed (fig. 1–15). Usually two or three neutrons are ejected from each fissioning nucleus; at least one neutron from each must cause additional fissioning. The newly ejected neutrons must do the same in a continual process. When conditions allow exactly one-fission per neutron, *criticality* is said to have been achieved. There are a number of hindrances to getting at least one neutron from each fissioning to produce another fissioning. Since most of the neutrons either escape from the fissionable mass or are captured by nonfissionable impurities, the isotope must have a certain "percentage of purity."

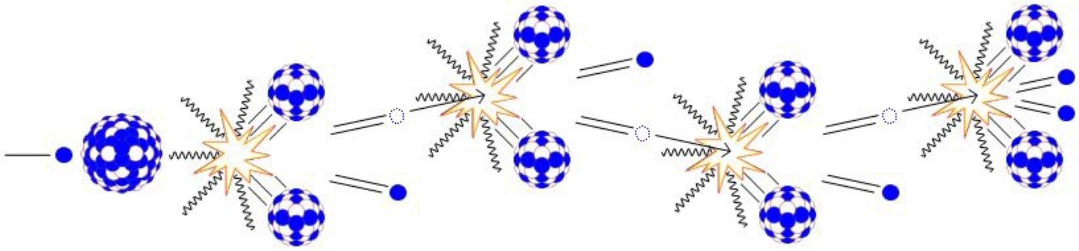


Figure 1–15. Self-sustaining chain reaction.

There is also a minimum mass of fissile material that will support criticality under given conditions: *critical mass*. For example, the critical mass for a bare sphere of metallic U–235 (93.5% pure) is 48.6 kilograms (kg), or 107 pounds (lb). The same sphere placed underwater requires only 22.8 kg (50 lbs) for a critical mass due to the reflection of neutrons provided by the H_2O. A spherical or cylindrical shape is most efficient in providing the least surface area for the volume of material, so that more neutrons interact and fewer escape. If the material is made denser, the targets for the neutrons will be closer together, increasing the chances of fission capture. The type of surrounding material determines whether neutrons are reflected back to the fissioning mass (increasing the effectiveness) or allowed to escape. The very things that enhance fission can of course lead to accidents. If storage, handling, and disposal procedures are not strictly followed, there can be a spontaneous initiation of the fission process.

It is important to understand that even the smallest quantities of isotopes are emitting a multitude of particles. It is the overall effect that these particles produce together that is important and not the specific interactions of any single one.

624. Radiation and radioisotopes (quantities and units)

There are several distinctly separate quantities used in radiation: a*ctivity, exposure, absorbed dose (D), and dose equivalent (H)*. Each of these quantities has a specific unit of measurement to describe it. This discussion will enable an understanding of the quantities used and how to apply their units properly. Refer to the table below to help clarify the concepts.

There are two different unit systems in place to describe the same quantities. The older unit system is simply called the conventional system, while the newer system is called the *Systeme Internationale*, or *SI*. The United States (US) is one of the few countries still using the conventional system of units. The Nuclear Regulatory Commission (NRC) regulations require that official records be kept in conventional units (Title 10 Code of Federal Regulations (CFR) 20.2101, *General Provisions*). However, it helps to be familiar with both unit systems. The following table identifies when each unit is used and how conventional units relate to SI units; information displayed in parenthesis is based on the conventional system.

Quantity	Name	Symbol	Units
Activity	Becquerel (curie)	Bq (Ci)	1 dps (3.7 x 10^{10}Bq)
Exposure	coulomb per kilogram (roentgen)	(C/kg) (R)	C kg^{-1} (2.58 x 10^{-4} C kg^{-1})
Absorbed Dose	gray (rad)	Gy (rad)	J kg^{-1} (10^{-2}Gy)
Dose Equivalent	sievert (rem)	Sv (rem)	J kg^{-1} (10^{-2}Sv)

Activity

The activity of a radioisotope is based on the number of disintegrations of RAM per a unit of time. Every isotope decays at a specific rate. The rate of decay (λ) is proportional to the stability of the nucleus; therefore, if an isotope is very unstable (such as fission products), it will decay very fast (within seconds or minutes). In contrast, if an isotope is very stable but still radioactive, it may take thousands of years to decay. Activity is mathematically expressed as a function of the λ and quantity of material expressed in the following equation:

$$A = \lambda N$$

Where:

A = activity (expressed in dps).
λ = isotope specific decay constant.
N = number (#) of radioactive atoms decaying.

The *activity* of a radioisotope can also be called source *strength*, *quantity*, or *radioactivity*. The conventional system of units uses the curie (Ci) to measure the activity. The Ci is a measurement of how many atoms are disintegrating in a given period of time.

$$1 \text{ Ci} = 37 \text{ billion dps} = 2.2\text{x}10^{12} \text{ disintegrations per minute (dpm)}$$

or

$$3.7 \times 10^{10} \text{ dps}$$

Theoretically, the higher the activity, the more transformations there are per unit of time and thus the greater the amount of radiation that is emitted. Routine BE radiation duties are more likely to deal with *millicuries* (mCi), *microcuries* (µCi), *nanocuries* (nCi), and *picocuries* (pCi) — listed from largest to smallest. The SI uses the term *becquerel* (Bq) as the measurement unit for radioactivity. Therefore, we have the following equations:

$$1 \text{ Bq} = 1 \text{ dps}$$

or

$$3.7 \times 10^{10} \text{ Bq} = 1 \text{ Ci}$$

The following table gives some common unit conversions:

Units of Activity and Conversions		
1 Ci	=	$3.7x10^{10}$ dps
1 Ci	=	$2.2x10^{12}$ dpm
1 Bq	=	1 dps
1 Ci	=	$3.7x10^{10}$ Bq
1 Bq	=	2.7×10^{-11}Ci
1 Ci	=	$1x10^{3}$ mCi
1 Ci	=	$1x10^{6}$ μCi
1 Ci	=	$1x10^{9}$ nCi
1 Ci	=	$1x10^{12}$ pCi
1 Bq	=	$2.7X10^{-8}$ mCi
1 Bq	=	$2.7X10^{-5}$ μCi
1 Bq	=	0.027 nCi
1 Bq	=	27.02 pCi

Various standards for limiting radiation materials to safe amounts (such as for transportation, storage, or waste disposal) are expressed in Cis. Note that the Ci or Bq, although used as a "unit" quantity, does not imply anything about the mass or volume of the RAM in which the specified number of transformations occur. The concentration of radioactivity (the relationship between the mass of RAM and the activity) is called the *specific activity* (SA). The most convenient way to calculate SA is making use of the fact that there are 3.7×10^{10} dps in 1 gram (g) of Ra–226, therefore:

$$SA\ of\ Ra–226 = 1\ Ci/g$$

SA is simply the number of curies per gram (Ci/g) of material. A nuclide must have an SA of more than 0.002 Ci/g (2×10^{-9} Ci/g) to be considered a RAM. A high SA indicates a potentially more dangerous isotope because a very small mass of such a material has many transformations per second and thus high radiation intensity. SA is directly related to a radioisotope's half-life. A shorter half-life means more transformations per second; and more transformations per second means more radiation. The ratio of the specific activity of any isotope (SA_i) to that of Ra–226 is described by the following equation:

$$SA_i = \frac{A_{Ra} \times T_{Ra}}{A_i \times T_i}$$

Where:

SA_i – (specific activity of isotope i) = Ci/g
A_{Ra} – atomic weight of Ra–226 =226
T_{Ra} – $T_{½}$ of Ra–226 = 1604 years
A_i – atomic weight of isotope i
T_i – $T_{½}$ of isotope i (must be in years)

There may be times when it is necessary to convert Bq to Ci. An example of converting Bq to Ci would be to convert 50 megabecquerel (MBq) to Ci. Using the conversion factor from above (*3.7×10^{10} Bq = 1 Ci*), multiplying by 50 MBq will look like the following:

$$(50x10^{6}\ Bq)\left[\frac{1\ Ci}{3.7x10^{10}\ Bq}\right] = 1.35x10^{-3}Ci = 1.35\ mCi$$

Radiological half-life

The *radioactive half-life* ($T_{½}$) is the amount of time needed for half of the “activity” to decay away. For example, the half-life of P–32 is 14.2 days. 100 Ci of P–32 today will have 50 Ci in 14.2 days, or half of the original activity. Inversely, if a sample is measured at 100 Ci today, it can be determined there was 200 Ci 14.2 days ago. Figure 1–16 is a representation of radioactive decay. The graph illustrates the λ for Tc–99^{m}, which has a half-life of 6.2 hours.

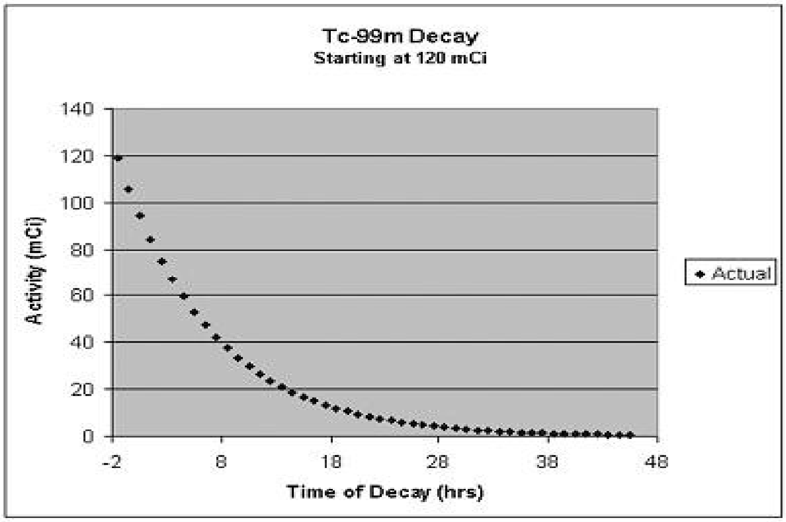


Figure 1–16. Tc–99m decay.

The $T_{½}$ can be used to calculate the amount of activity at any point in time, given the activity at another point in time. Being able to do this could be useful when needing to calibrate equipment with an ‘expired’ check source. This can be done with the following equation:

$$A = A_0 e^{-0.693t / T_{1/2}}$$

Where:

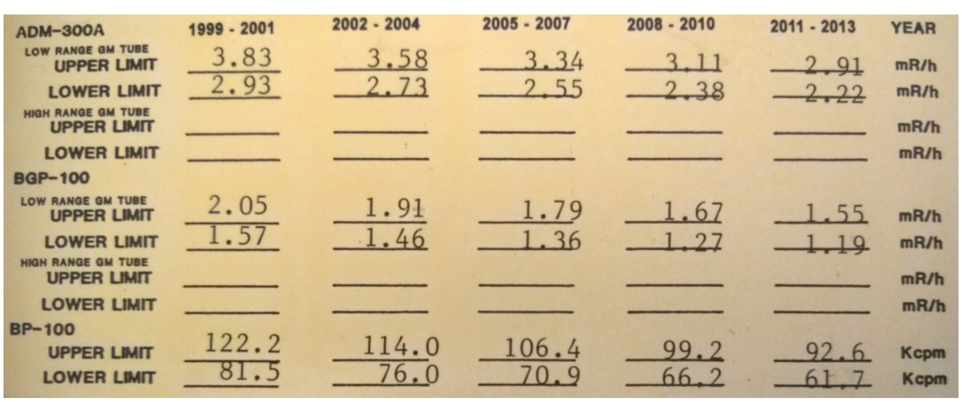
A = Activity at time t

A_0 = Initial activity

$T_{1/2}$ = Radiological half-life of material

t = Amount of time between A_0 and A (must be same units as $T_{1/2}$).

As an example, an ADM–300 Beta Probe (BP)–100 probe needs to be calibrated in 2020, but the only available check source has the information shown in fig. 1–17. What is the acceptable lower limit for this probe?



ADM-300A	1999 - 2001	2002 - 2004	2005 - 2007	2008 - 2010	2011 - 2013	YEAR
LOW RANGE GM TUBE UPPER LIMIT	3.83	3.58	3.34	3.11	2.91	mR/h
LOWER LIMIT	2.93	2.73	2.55	2.38	2.22	mR/h
HIGH RANGE GM TUBE UPPER LIMIT						mR/h
LOWER LIMIT						mR/h
BGP-100						
LOW RANGE GM TUBE UPPER LIMIT	2.05	1.91	1.79	1.67	1.55	mR/h
LOWER LIMIT	1.57	1.46	1.36	1.27	1.19	mR/h
HIGH RANGE GM TUBE UPPER LIMIT						mR/h
LOWER LIMIT						mR/h
BP-100						
UPPER LIMIT	122.2	114.0	106.4	99.2	92.6	Kcpm
LOWER LIMIT	81.5	76.0	70.9	66.2	61.7	Kcpm

Figure 1–17. ADM–300 check source data.

The RAM used to calibrate the probe is Cs–137, with a half-life of 30.167 years. Since it has been 21 years since the original measurements of the check source (1999–2020), the equation is:

$$A = (81.5\,Kcpm)e^{-0.693(15)/30.167}$$

$$A = 57.7\,Kcpm$$

Therefore, the lower limit for the ADM–300 BP–100 probe in 2020 is 57.7 thousand counts per minute (Kcpm). The same calculation can be done for the upper limit, yielding 86.6 Kcpm. With this knowledge, operations do not have to stop, since calibration of the probe can be done with the current check source.

Biological half-life

Just as RAMs decay at a predictable rate (based on the radiological half-life), they are also cleared from the body at a predictable rate, known as the *biological half-life* (T_b). The remaining RAM in the body can be calculated with the following equation, which is very similar to the radioactive decay calculation:

$$A = A_0 e^{-0.693t/T_b}$$

NOTE: The only change to the equation is using T_b instead of $T_{1/2}$.

Effective half-life

The combined effect of the RAM decaying and the biological clearing of the material is known as the *effective half-life* (T_{eff}). The T_{eff} will always be less than or equal to the shorter of the radioactive or T_b, and can be calculated as follows:

$$T_{eff} = \frac{T_{1/2} \times T_b}{T_{1/2} + T_b}$$

Given two compounds with relatively short half-lives, the T_{eff} can be significantly shortened, as demonstrated by the following equation:

$$T_{1/2} = 8\,days\; T_b = 14\,days : T_{eff} = \frac{8 \times 14}{8 + 14} = 5.1\,days$$

However, if the half-life of one is significantly longer than the other, the shorter half-life will govern the T_{eff}, as shown in the following equation:

$$T_{1/2} = 8\,days\; T_b = 30\,years\;(10{,}958\,days) : T_{eff} = \frac{8 \times 10{,}958}{8 + 10{,}958} = 7.99\,days$$

Knowing the T_{eff} can be important when determining total exposure of internal radiation.

Exposure

The *exposure unit* (sometimes called exposure dose) to ionizing radiation seen most often is the *roentgen (R)*. The *exposure rate* is the exposure divided by units of time, such as *roentgen per hour* (R/hr), or *milliroentgen per hour* (mR/hr). R is the amount of X-ray or gamma radiation that will produce 2.58×10^{-4} C/kg of air. In the SI system, there is no special name for the quantity exposure; instead, units of C/kg are used (coulomb, represented by "C," is a unit of electrical charge). The following equation shows the relationship between Rs and C/kg:

$$1\text{ R} = 2.58 \times 10^{-4}\text{ C/kg}$$

There may be times when it is necessary to convert Rs to C/kg. Applying this equation to an example, convert 3 R to C/kg. Multiply 3 R by the conversion factor to obtain the following:

$$(3\ R)\left[\frac{2.58x10^{-4}}{R}\right] = 7.74x10^{-4}\ {}^{C}/_{kg}$$

Instruments used to measure quantity of exposure, or number of ions produced in air, determine exposure in air. The instruments normally used to measure radiation read in units of exposure rate (a measure of the ionization produced in air by X-rays or gamma rays per unit of time, also known as intensity) rather than simple R. The exposure rate (R/hr or mR/hr) and the period of exposure are used to determine total exposure and estimated dose. Most radiation work exposures are very small, so mR/hr is the exposure rate most often used. These instruments cannot determine the amount of energy absorbed in matter (human tissue), nor can they be applied to the particulate radiation (alpha, beta, and neutron).

Absorbed dose

The quantity that indicates how much energy was absorbed in matter is the D. It is simply the amount of energy absorbed per unit mass of material. The D is a much more useful quantity in many circumstances because it is applicable to any type of absorbing media and any type of ionizing radiation. The unit used most often is called *rad* (for one dose of *ionizing radiation*). The rad is defined as a unit of D of ionizing radiation equal to an energy of 100 ergs per gram (ergs/g) of irradiated material, as shown here:

1 rad = 100 ergs/g

In the preceding equation, "ergs" are measures of energy (ergs of energy) equal to 10^{-7} joules and "g" is a mass of material (human tissue). Therefore, as ionizing radiation enters the body, energy is deposited into the tissue. The conventional unit of energy is joule. Therefore, the conventional unit of D is equal to 0.01 joule per kilogram (J/kg) and the *SI* unit for D is the *gray* (Gy). The following equation shows the conversion factors for joule, Gy, and rad:

1 J/kg = 1 Gy = 100 rad

It is important to remember that *dose* and *exposure* are *not* the same thing. However, they are related through a *dose equivalent* (H).

Dose equivalent

The need to control the relative risks of different types of radiation is the reason for the dose equivalent. The purpose of the dose equivalent is to assess and control risk from various types of radiation. Each type of radiation is assigned a quality factor (Q) that reflects its associated potential to cause biological effects. (Q is a dimensionless factor, meaning it has no units.) Qs, or *radiation weighting factors* (W_R), are used to determine the dose equivalent in *roentgen equivalent man* (rem) from the dose in rads. The following table provides a comparison for each:

Radiation	Q	W_R
X-ray, gamma, beta	1	1
Neutrons < 10 keV	2	5
10 keV to 100 keV	5	10
>100 keV to 2 MeV	10	20
>2 MeV to 20 MeV	8	10
>20 MeV	5	5
High energy protons	10	5
Alpha particles, fission fragments, heavy nuclei	20	20

The relationship between D and H is simply the D in *rad* multiplied by Q:

$$H = DQ$$

The SI unit of dose equivalent to humans is the sievert (Sv); however, the unit most likely seen is rem. The rem is a dose equivalent term which allows comparison of the damage caused by different types of radiation. The preceding table shows that alpha particles have the highest *Q value* (20). That is because they create the most ionizations per unit path length.

Not only have neutrons been found more effective than X-rays in producing cataracts, alpha radiation too has been found to be more toxic per D unit than beta or gamma radiation. In comparing the relative toxicity or damage-producing-potential of a given D of various radiations, it has been found that the higher the rate of LET of the radiation, the more effective it is in producing biological damage. LET is expressed in energy units of kiloelectron-volts per micron (keV/µ) of path. When expressing the energy dissipation in this unit keV/µ, the values range from 3.5 or less for X-rays and electrons to well over 100 for heavy ionizing particles (see the following table).

LET Versus Q Factor	
LET (keV/µ in water)	Q
3.5 or less	1
3.5 – 7.0	1 – 2
7.0 – 23	2 – 5
23 – 53	5 – 10
53 – 175	10 – 20

While the dose equivalent is an estimate of the damage that radiation can do to human tissue, it is also important to know how radiation can affect other forms of matter. Radiation interactions are important in determining the potential for damage to body tissues and in providing a basis for detection methods and shielding requirements.

Properties and common uses of specific isotopes can be found in numerous sources. For those of particular interest to the AF that bioenvironmental engineering (BE) personnel are likely to encounter, see Supplement 2 of the Bioenvironmental Engineer's Guide to Radiological Emergencies found at https://hpws.afrl.af.mil/dhp/OE/ESOHSC/pages/index.cfm?id=428, which is the Environment, Safety, and Occupational Health (ESOH) Service Center website.

625. Biological effects of ionizing radiation

The human body has the tremendous ability of producing new cells to replace those that have died or have been damaged. Studies have shown that the human body can tolerate a certain amount of exposure to ionizing radiation without its overall functions being impaired. The term dose is generally used to express a "measure of radiation" that the body absorbs when exposed. The possible effects of radiation vary relative to the amount of dose received, type of effect, time involved, and other factors. The causes are ionization of atoms within body cells, and the specific mechanisms of action they produce in cells, are of special interest in understanding what damage may occur and why.

Cell damage

Changes to the atomic structure of atoms in body tissue can cause cell damage. Since tissues and organs are collections of cells, the interactions between cells are responsible for the health of the entire body. Figure 1–18 shows the basic structure of a typical body cell. Body cells that reproduce into the same type of cell are called somatic cells (this is different from cells that may reproduce to form a different type of cell, such as stem cells). Somatic cells are also called "body cells" because the human body is mostly made up of somatic cells.

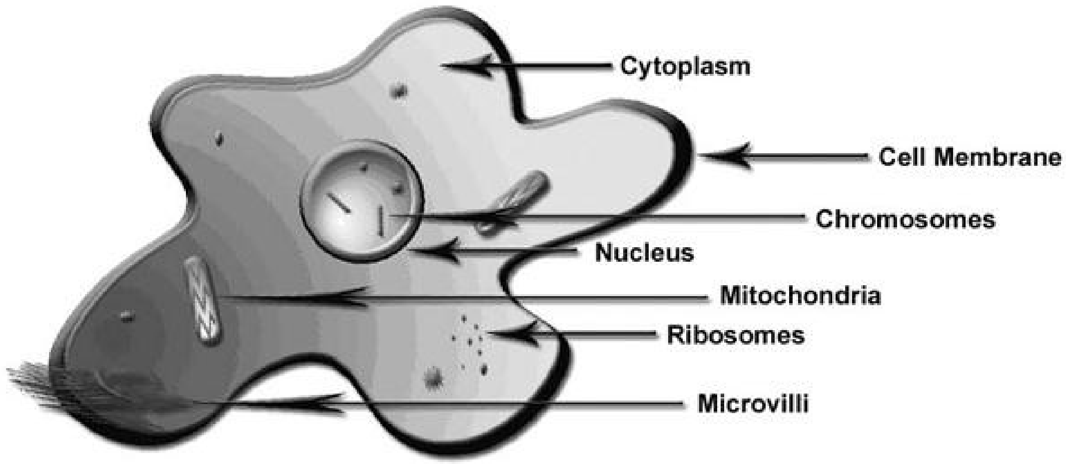


Figure 1–18. Body cell.

The liver, heart, and hands are made entirely of somatic cells, and these are only a few examples. To better understand how radiation affects a cell, it is necessary to review some cell structure and actions. The bulk of body cells are composed of a watery fluid called *cytoplasm*. The cytoplasm is surrounded by a cell membrane that holds the cell together. Within the cytoplasm is the nucleus, that contains most of the cell's regulatory and reproductive elements, called *chromosomes*. Human somatic cells have 23 pairs of chromosomes that contain strands of large deoxyribonucleic acid (DNA) molecules; these molecules contain codes for hereditary characteristics and the controls for cell function. Most cells have a limited life span and must divide at a certain stage to produce daughter cells. The information in the DNA molecules enables the cell to produce a daughter cell that is like the parent cell in every way.

Cell structures can be damaged or impaired by ionizing radiation. This can occur through either *direct radiation effect* or *indirect radiation effect*. Direct damage to a cell occurs when radiation collides with or passes close enough to a molecule in the DNA, causing it to dissociate (break apart). This dissociation, caused by ionizing an atom on the DNA chain, may cause cell death or prevent the original gene information from being correctly transmitted to the next generation. About 20 % of the cell damage is from direct radiation effect. The other 80 % is by indirect radiation effect. With indirect radiation effects, a chain reaction is started. An ionized molecule creates a new molecular structure that is very chemically reactive. These reactive materials are called free radicals that react with and change nearby materials, which in turn damage the cell. Most of the body is made up of H_2O and as such, most of the indirect radiation effect is on H_2O. Most often, H_2O becomes ionized, making it a free radical that reacts with nearby material, forming hydrogen peroxide (H_2O_2) which is toxic to cells. This ionization of H_2O causes a series of dissociations, which in turn produce many other free radicals and several other harmful compounds (as illustrated with H_2O_2). The highly reactive products diffuse from the ionization site and interact with molecules in other areas of the cell. Most such reactions do not cause any real trouble; however, the potential for severe damage remains when sensitive molecules such as DNA are involved.

With high radiation doses, some cells are killed immediately and release a variety of chemicals some of which are toxic to other cells. Often, a cell will repair itself; if not, it may suffer serious effects. One serious effect that radiation can have on cells is the delay of cell division (fig. 1–19). Such a cell may continue to grow until it reaches an abnormal size and then die without any replacement cells to assume its functions. This "reproductive death" is the most common effect of large radiation doses. Another possibility is that the irradiated cell may be altered, so that its daughter cells are genetically altered (different). The new cells may in turn die before reproducing themselves, continue to grow without dividing, or divide at a slower or faster rate than the parent cell.

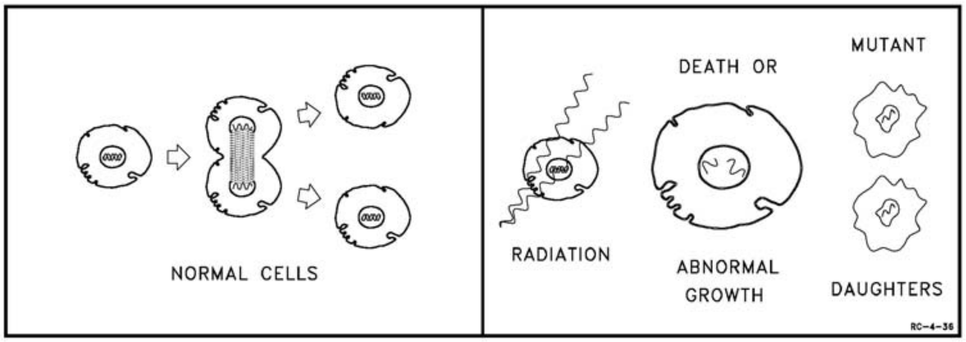


Figure 1–19. Cell damage due to radiation.

Since the DNA faithfully reproduces all characteristics of the parent in new cells, a parent with an altered DNA structure will pass along its mutant characteristics to all descendants. The faulty DNA information may eventually allow uncontrolled cell division (resulting in cancer of the irradiated tissue). If a reproductive cell (a sperm or an ovum—the opposite of somatic cells) becomes genetically altered, its offspring might also have this same mutated alteration. The consequences may range from no observable effects in the offspring to quite serious abnormalities, and may continue to be passed from generation to generation.

The human body is an integrated assembly of organ systems whose structures are in accord with their functions. Each organ system is made up of several different types of tissues, and each tissue has somatic (specialized) cells that perform specific functions. Cells differ not only in appearance and function, but also in their response to radiation. The cells most susceptible to damage are those that reproduce most rapidly (such as the cells of blood-forming tissues) and those that are not fully mature when hit by radiation. Cells are also more susceptible while they are dividing as compared to when they are not (resting). Therefore, the fetus, especially during its first three months of existence, is at much greater risk from radiation exposure than an adult. During fetal development, a low radiation dose has more potential to cause health problems (effects) than adults who may withstand a more significant dose.

Relating dose to response

The biological effects of ionizing radiation are often classified as being either *stochastic* or *deterministic* (*nonstochastic*) in their nature. Most of the effects that can directly be observed are of the *deterministic* or threshold type, which means that there is no apparent reaction, or a given condition is not seen, until a certain threshold dose is reached. This is illustrated in line B of fig. 1–20.

Deterministic effects are characterized by the following three qualities:

- A certain minimum dose must be exceeded before the particular effect is observed.
- The magnitude of the effect increases with the size of the dose.
- There is a clear, unambiguous causal relationship between exposure to the agent and the observed effect.

A good example of this would be alcohol. A person must exceed a certain amount of alcoholic intake before he or she shows signs of intoxication. After that, the effect of the alcohol depends on the person’s rate of drinking. Finally, if this individual exhibits drunken behavior, there is no doubt that the behavior is the result of drinking. (Cember & Johnson, 2009) Another example is exposure to sunshine. Most people can tolerate a certain amount of exposure to sunlight with no effect, but eventually they will reach a dose that result in sunburn. The response becomes greater as the dose is increased. *Deterministic* radiation effects can be clearly observed as being caused by radiation exposure; for example, massive blood changes, nausea, and fatigue in the individual.

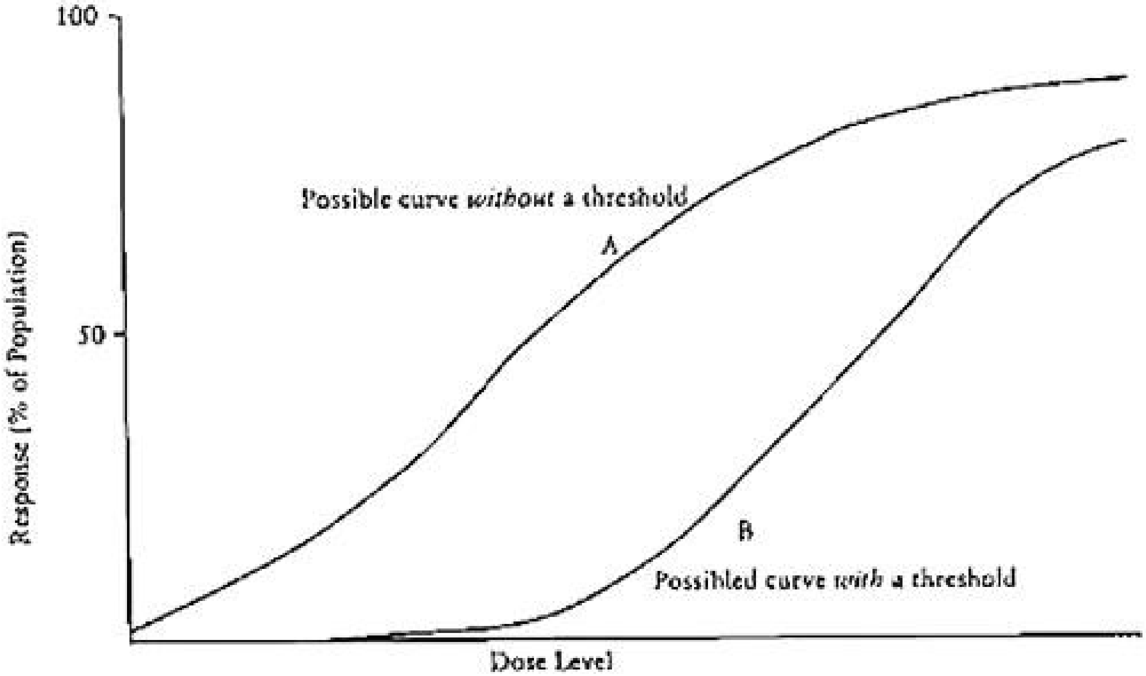


Figure 1–20. Dose-response curve.

In contrast, *stochastic* effects without a threshold dose do not show a clear relationship to the dose received. Stochastic effects are "all-or-nothing," such as cancer. The severity of the effect is not dose related, though the probability of it occurring may be. There is no threshold below which the probability of effect is zero. For example, many people that have little or no radiation exposure get cancer, and it is also true that many people who have had considerable exposure never get cancer. It is impossible to say with absolute confidence that radiation caused someone's cancer. Therefore, only inferences can be made, such as "an increased incidence of cancer (and usually of a specific type) among certain radiation exposures." According to the stochastic concept, any radiation dose, no matter how small, causes some change, although the consequences of the change may be unknown. Validity of this concept is given by the fact that a single gamma ray can alter a cell's DNA. The result may be unobservable or become a serious problem. It is the uncertainty involved that has led to the practice of keeping exposures "as low as reasonably achievable" (ALARA). "Reasonably" should be emphasized because many people overreact where radiation exposure is concerned and try to impose wasteful, unrealistic controls where they are not necessary. ALARA will be discussed later in this unit.

Whether stochastic or deterministic, the magnitude of the dose affects the type and severity of radiation effects on any given person. The individual receiving the dose is another variable; among humans, there is much difference in sensitivity due to such things as age, general state of health, and simple natural variability. There are also great differences in the sensitivities of various organ systems. Further a distinction needs to be made between *irradiation of a single organ* and a *whole-body exposure*. For example, a very large dose can be applied to a small part of the body during radiation therapy without causing systemic damage; however, such an exposure to the entire body might prove fatal. Both individual organ and whole-body exposures can be caused by internal or external irradiation.

Internal radiation

Internal radiation is from RAMs that have entered the body. Any type of radiation from a radioisotope that gets inside the body has the potential to cause severe damage because there is no protective layer of skin and other tissues to help protect against it. Some nuclides enter the body by inhalation, injection, absorption or ingestion, and are spread throughout the body, causing whole-body exposure. Most nuclides, however, become localized in a preferred organ, such as the thyroid or bone marrow, and the damage is largely confined to that area.

External radiation

External radiation exposure, on the other hand, is limited primarily to the types that can readily pass through the skin: gamma, X-ray, neutrons, and sometimes beta. An external dose can be delivered to one small area of the body (again as in radiation therapy) or, more often, the entire body is irradiated (usually by accident). Low-energy gamma and X-rays tend to affect mainly the skin as does high-energy beta, whereas higher energy gamma and X-rays can penetrate further to reach the interior of the body.

A large exposure to a single organ can be tolerated much more easily than the same exposure to the whole body. Similarly, a large exposure can be tolerated if it is delivered over many years but would kill if the same exposure was delivered in only a few minutes. This brings up the difference between *acute* and *chronic* exposures.

Acute exposure

An acute exposure is one in which a person receives a dose in a short period of time. Unfortunately, "short time" is ill-defined (i.e., it may be essentially instantaneous or last many hours). One reference uses an arbitrary period of 24 hours, but large doses received over many days or even weeks may be considered acute in some cases. The key is that acute refers to a single exposure. Fortunately, acute radiation exposures are rare and typically related to significant accidental exposures and nuclear warfare.

Chronic exposure

Chronic most often deals with small doses received over many years (as seen with radiation workers). Although chronic radiation exposure is linked to increased risk of cancer, genetic changes, and cell malfunction, the cause and effect relationship is not well understood. That is, effects cannot be specifically ascribed to exposures.

Acute radiation syndrome

The symptoms of *acute radiation syndrome* (ARS) depend on the dose received over the whole body. They are grouped into three separate "sub-syndromes" which are generally related to dose level and effect on body systems, specifically, the circulatory, intestinal, and central nervous systems (CNS). As ARS develops, the progression of these effects occurs in four stages. When an individual has a dose high enough to develop ARS, the observable illness will start with the *prodromal stage*, progress next through a *latent stage*, and then ultimately the body system effects occur in the *manifest stage*. If the victim is fortunate, these stages are followed by the *recovery stage*. The higher the dose, the faster the victim progresses through these stages. The length of progression time ranges from hours after a very high dose to weeks after a lower dose.

Prodromal stage

During the prodromal stage the body outwardly expresses initial symptoms of exposure. This stage occurs during the first few hours after exposure, characterized by nausea, vomiting, and malaise (general feeling that something is wrong). It does not predict the degree of radiation injury but suggests a life-threatening exposure has occurred.

Latent stage

The latent stage, during which the patient is relatively symptom free, follows the prodromal stage. The length of this stage varies with the dose but can last from several hours up to six weeks.

Manifest stage

The manifest stage, when body system effects start to appear, begins after the latent stage. Rapid progression to the manifest stage indicates a very high exposure.

The effects seen in the manifest stage are named after the body system most affected. Remember that ARS typically progresses through the prodromal stage, the latent stage, and then manifests with the main body system effects for each of the three sub-syndromes as shown in figure 1–21. The progression begins in the hematopoietic system (blood forming), then the gastrointestinal (GI) system, the pulmonary system (lungs), and then the CNS.

ARS Phase	Parameter	Acute Whole-Body Dose cGy (rad) External Gamma Dose					
		0–75	75–200	200–600	600–800	800–3000	>3000
Prodromal Phase	Nausea, Vomiting	0–5%	5–50%	50–100%	75–100%	90–100%	100%
	Time of Onset	3–6 h	3–6 h	2–4 h	1–2 h	<1 h	<<1 h
	Duration	<24 h	<24 h	<24 h	<48 h	48 h–4 d	2–7 d
	Impairment	Minimal	Minimal	Yes	Yes	Yes	Yes
Latent Phase	No Symptoms	> 14 d	7–15 d	0–7 d	0–2 d	None	None
Manifest Illness Phase	Time of Onset	N/A	>14 d	2–14 d	2–14 d	1–3 d	1–3 d
	% Hospitalized	0%	<5%	90%	100%	100%	100%
	Hospitalization Duration	None	45–60 d	60–90 d	>90 d	Weeks to months	Days
Fatality	No Treatment	0%	0–<5%	5–60%	60–90%	90–100%	100%
	Time to Death	N/A	42–49 d	42–49 d	21–49 d	3–21d	2–7 d

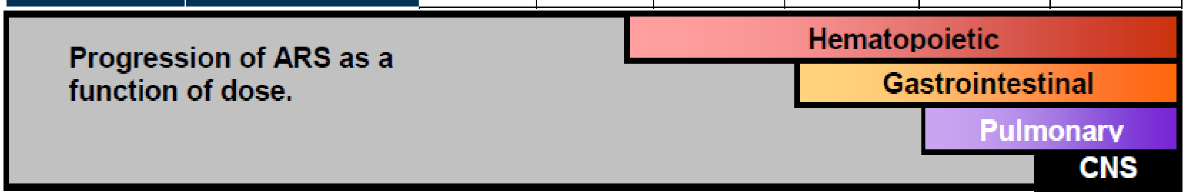


Figure 1–21. Summary of ARS.

It takes a significant acute radiation exposure of 0.25–1 Gy (25–100 rad) to initially identify that effects are occurring in the body. At this level, some changes in blood can first be seen. Most individuals may not even have any outward symptoms and might not become physically sick. Although there may be no outward symptoms, the rapidly reproducing blood cells are affected and clinical blood tests would indicate a decreased number of different blood cells. This dose is not considered immediately life threatening, but it normally takes several months for the blood count to return to normal. ARS generally occurs when an ionizing radiation dose is greater than 1 Gy (100 rad).

Hematopoietic sub-syndrome

An acute whole-body dose of about 1–2 Gy (100–200 rad) is the point at which a victim experiences physical sickness from acute radiation exposure. This begins with the hematopoietic sub-syndrome. The latent period may last one to three weeks, during which there are few or no effects. The main illness that manifests is from blood-forming organs, especially the bone marrow that cannot create cells to maintain circulatory functions. This results in loss of appetite, fatigue, nausea, vomiting, and increased susceptibility to infections. The severity of the effects naturally increases with increasing dose or exposure times. Fortunately, most people receiving doses in the 1–2 Gy (100–200 rad) range do not require much medical care (other than observation) and death is unlikely.

Doses of 2–10 Gy (200–1,000 rad) still affect the circulatory system and contribute to the hematopoietic sub-syndrome. At these levels, over half of the victims suffer hair loss and experience a moderate illness requiring medical attention. Without medical care, nearly half would be expected to die within 60 days. An acute dose of 450 rem (4.5 Sv) is often listed as that dose which kills 50% of the untreated exposed people within 60 days after the exposure. This lethal dose (LD) is expressed as the LD–50 or LD_{50}. There are no humans known to survive a dose greater than 6.5 Gy (650 rad) without treatment. Even with treatment, at a dose between 6–10 Gy (600 to 1000 rad), greater than 90% of the victims are expected to die of internal bleeding and infection within one to six weeks.

Gastrointestinal sub-syndrome

When doses reach 10–50 Gy (1,000 to 5,000 rad), significant damage to the GI tract will occur. This can sometimes begin at 6 Gy (600 rad). The GI sub-syndrome includes all the effects of the hematopoietic sub-syndrome and additionally produces severe nausea, vomiting, and diarrhea almost immediately after exposure. When the dose is high enough to seriously affect GI cells, symptoms will manifest in a few days to over a week. This is a fatal dose because the amount of radiation required to damage a large portion of GI cells usually kills most of the blood forming cells and further compromises bodily functions.

CNS sub-syndrome

Doses above 50 Gy (5,000 rad), and possibly even as low as 20 Gy (2,000 rad), either stops cellular reproduction or outright kills body cells, causing damage to the CNS and every other organ in the body. This CNS sub-syndrome produces convulsions and unconsciousness within minutes of exposure, and death from respiratory failure and brain edema within a few hours to two days.

Delayed effects that a survivor of ARS may experience can appear many years after exposure. Essentially, the same problems attributed to chronic exposures are noted: primarily an increased risk of cancer (mainly leukemia), cataracts, shortened life span, and accumulated genetic defects that may adversely affect later generations. These are the nonstochastic type of effects discussed earlier.

In general, the risk of high acute exposures occurring in the AF is low. However, BE shops must be cognizant of the health consequences in the event of an attack or accident involving ionizing radiation.

626. Sources, use, and production of X-rays

In addition to naturally occurring radiation, background radiation, and RAMs, exposure from man-made radiation sources must be considered. For instance, older television sets (or other instruments with significant acceleration and deceleration of electrons) can generate small amounts of X-rays. Most of us are familiar with diagnostic imaging in medicine that uses X-rays to view internal organs. When man-made radiation is produced, public doses must be limited or controlled.

X-rays are produced when projectile electrons interact with either the target material's nuclei or orbital electrons. This principal radiation is bremsstrahlung (fig. 1–22) and occurs when electrons pass the target nuclei at different distances and thus give up different amounts of energy as X-rays. This results in a continuous spectrum of X-ray energies, a wide range from the lowest to the highest energies.

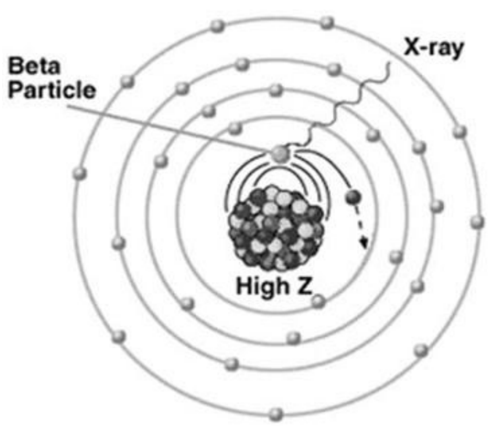


Figure 1–22. Bremsstrahlung radiation.

Production and use of X-rays

X-ray production is electrons that are intentionally accelerated into a material with a high atomic number for the purpose of bremsstrahlung interactions to generate X- ray photons.

Before learning about evaluating X-rays, the basics of X-ray operations, to include the X-ray unit itself (fig. 1–23), must be understood. This not only enables recognition of what needs to be done during a survey, but also increases knowledge of the duties of an X-ray technician, allowing discussion of important aspects of the job.

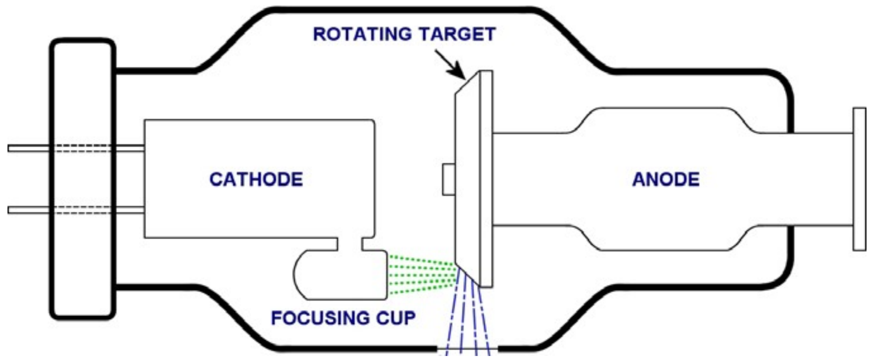


Figure 1–23. X-ray tube interior.

X-ray tube

At the heart of every X-ray machine is the X-ray tube that converts electrical power to useful X-rays used to expose film or collect on digital receptors. Radiographic X-ray machines (those using film or digital imagery) are shown, but similar tubes are used in *fluoroscopes* (real-time video imaging). The main difference is that fluoroscopes use a fluorescent screen rather than film or digital plate to allow a physician to see what occurs inside a patient while it is happening. The X-rays pass through the patient to the screen to form images. The X-ray tube consists essentially of a glass envelope which encloses a *cathode* and an *anode*.

Cathode

The effective part of the cathode is a *negatively* charged filament (often made of tungsten because of its high melting point), and that emits electrons when heated sufficiently. Most modern tubes have two different size filaments for different modes of operation. They are found inside a *focusing cup* (also negatively charged), which helps direct and propel electrons toward their target on the anode. As the electrons leave the filament (only one filament is in operation at a time), they have a tendency to spread out so that many would miss the target (resulting in unnecessary exposures) if they were not properly controlled by the focusing cup.

Anode

The anode is charged *positively* to attract the electrons from the cathode and usually has a rotating disc that acts as a target for the electrons. It serves as an electrical conductor, a thermal conductor, and a target support. As an electrical conductor, it completes the circuit for electron flow from the cathode back to the high voltage section of the X-ray machine. As a thermal conductor, the anode must remove the heat quickly away from the target before the target is damaged. Tungsten is used as the target material, as well, for its high resistance to heat damage and for its high atomic number for efficient X-ray production. The target rotates to prevent melting; this allows the part of the target not being hit with electrons to dissipate heat. Low-power X-ray tubes (like those used in dental X-ray machines) do not have rotating targets. Instead, the targets are angled—the greater the angle, the larger the area that will be covered by the X-rays.

The *focal spot* is the area of the target bombarded by the electrons at any moment in time, the exact point where the X-rays begin. Consequently, the focal spot is the logical point from which to begin distance measurements. The size of the focal spot has a great deal to do with the coverage by the X-ray field (a large focal spot gives greater coverage), image quality (a small focal spot gives sharper image), and heat production (a large focal spot increases heat). Having the focal spot sized correctly for the task will significantly reduce unnecessary radiation exposures.

X-ray production

When fast-moving electrons (or beta particles) slam into a metal object, X-rays are produced through bremsstrahlung. The function of the X-ray machine is to provide sufficient intensity of electron flow from the cathode to the anode, in a controlled manner. As the negatively charged electrons leave the cathode, they are accelerated toward the attraction of the anode's positive charge. The larger the difference between negative and positive charge (the greater the voltage between them), the stronger the attraction. The greater the voltage potential between them, the more the electrons are accelerated, resulting in more energetic X-rays.

Machine parameters

Milliamperes (mA) and the kilovolt peak (kVp) control the number and speed of the primary electrons when generating X-rays. This means they have a great deal to do with controlling radiographic exposure parameters such as film density and contrast. In X-ray imaging, mA refers to the current (the number of electrons per unit time) moving from the cathode to the anode. Increasing the mA setting on an X-ray machine causes the filament to heat up more, to send out more electrons, which results in more X-rays and more exposure. The kVp setting controls the voltage (in kilovolts) between the cathode and the anode, and thus the speed or energy of the electrons. The use of *higher* kVp settings produces more penetrating X-rays, *reducing* patient exposure; that is, more of the energy passes through the patient rather than interacting with the patient's cells. However, higher settings can increase scatter radiation, which can fog film and increase exposure to the X-ray technician. These two machine parameters offset one another to some degree. For example, increasing the kVp while decreasing the mA can produce about the same film exposure as reversing the settings in many cases. Operationally, using higher mA or kVp settings for too long can also cause extra wear on the X-ray tube (due to heat). Figure 5–24 illustrates mA and kVp.

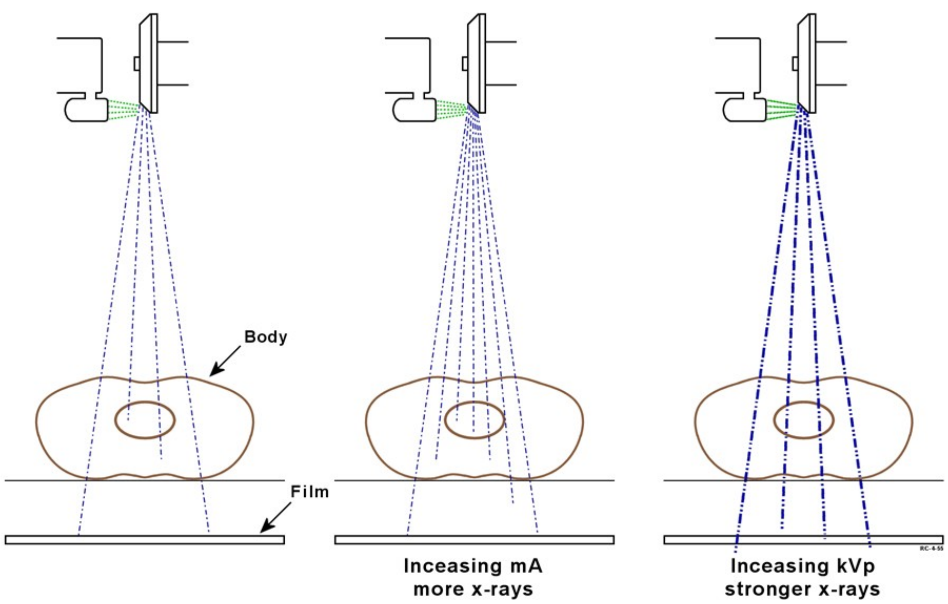


Figure 1–24. Parameters (mA and kVp).

Glass envelope

As previously stated, surrounding the cathode and anode is the "glass envelope" that is made of leaded glass to filter out some of the lower energy photons. The interior is kept under a partial vacuum to minimize interactions with air molecules and also to help slow down the eventual burnout of the tube. The "window" is the portion of the envelope through which the more useful X-rays exit the tube. The window is thinner than the tube and allows passage with less absorption.

Protective housing

The protective housing, along with its X-ray tube, oil bath, cooling fan and filtration, make up what is called the *tube head*. One of the main purposes of the housing is shielding. Although the tube is designed to direct X-rays in a single direction (through its window), a number of photons travel in all directions and do not contribute to the primary or useful beam. Potential radiation leakage from a tube head may cause unnecessary exposures and is one major concern during X-ray surveys. The shielding built into the tube head to prevent this leakage is termed *inherent filtration*.

Collimator

W is a device that provides an adjustable opening that restricts the X-ray beam to the smallest area consistent with clinical requirements. The use of a collimator is another way to keep patient exposures as low as possible due to smaller body areas receiving doses. Therefore, only the exact sections needing examination are irradiated. Collimation has a benefit of reducing scatter radiation and improving the radiographic image. Incidentally, the main concern for good quality radiographs is that excess exposure to patients is reduced since the need for repeating X-rays is eliminated.

X-ray machines range from the familiar medical and dental types to the high-powered devices used to check aircraft and missile parts in industrial radiography. With such a variety of possibilities for exposure, it is necessary to keep an accurate inventory of all sources and periodically evaluate each potential hazard.

Machines used in medicine

Low-energy X-ray machines are used primarily for diagnostic purposes in medical and dental clinics. Diagnostic machines are generally used for fixed, short-pulse duration procedures (conventional) and fluoroscopy, where the exposure duration is controlled real-time by an operator. For most machines used in the medical and dental clinics, the tube electric potential is between 50 and 150 kVp. For mammography machines, tube electric potential is typically between 25 and 45 kVp, dependent on the target material and image receptor. In diagnostic equipment, filtration is a critical component that reduces the radiation exposure to the patient of X-ray energies that provide no useful diagnostic benefit. Higher energy X-ray machines and X-rays produced from dual-purpose linear accelerators (i.e., emit X-rays or electrons) may be used for diagnostic procedures or radiation therapy. The peak X-ray energies typically are in the range of only a few to as much as 25 MeV.

Industrial X-ray NDI machines

X-ray machines used in NDIs are the most common type of X-ray machine in the AF, outside of the clinic. The units and specifications are generic and may not be representative of units that have been modified or updated.

Research/laboratory related X-ray machines

The AF has a significant number of machines that produce X-rays in the research and laboratory environments. Among the more significant sources in terms of exposure potential are the sources used to test the radiation effects on materials, most commonly electronic components being tested for radiation vulnerability. High radiation exposure over prolonged periods is often produced by radioisotope irradiators. However, extremely high radiation fields over very short periods of time are usually produced by high power flash X-ray systems. Most of these devices use electrons with peak energy from a few to 10 MeV. Low-power X-ray systems may be used in laboratory settings for analytical procedures like X- ray fluorescence. These devices, in general, are low hazard.

Baggage inspection and other systems

Baggage inspection systems are common to AMC terminals and other organizations that must perform security screens of hand-carried bags. X-ray systems used in AF operations are similar to those common to airport security inspection systems. Most systems have a conveyor belt that transports items intended for inspection under an X-ray beam that is directed downward. The systems typically operate at about 150 kVp. AF office of special investigations (OSI) and explosive ordnance disposal (EOD) organizations use portable X-ray machines periodically. These devices are low hazard, unless in the main beam.

X-ray generation incidental to high electric potential equipment

There are some AF devices that produce photons incidental to operation. Among the most important devices due to the high energy and frequency of use are electron particle accelerators used in medicine and radiation effects on materials testing. The range of electron energies for these devices is typically between a few and 35 MeV. All these devices produce bremsstrahlung and characteristic X-rays, and prompt γ-radiation. For accelerator energies above 10 MeV, neutron production is an important consideration, as is the activation-produced RAM that has delayed radiation emissions. Long-lived RAM may include isotopes being dependent on beam energy, materials in proximity to the beam, and target materials. For these devices, a health physicist's evaluation should be made.

627. Radioisotope permit program

The NRC is the primary federal agency that regulates RAM and its rules are found in Title 10 of the Code of Federal Regulations (CFR). The Department of Transportation (DOT) and the Environmental Protection Agency (EPA) also regulate some aspects of RAM.

Types of materials regulated

Specifically, the NRC regulates *source material*, *special nuclear material (SNM)*, and *byproduct material*. Of the more than 20,000 active source, byproduct, and SNM licenses in place in the US about a quarter are administered by the NRC, while the rest are administered by the 37 Agreement States. The NRC ensures that its materials program complies with the National Environmental Policy Act (NEPA) by conducting NEPA reviews for all major actions within the program.

Source materials

Source materials are those that can be used to generate SNM. They consist of uranium or thorium, or any combination of both, in any physical or chemical form, but which do not meet the requirements for SNMs.

Special nuclear materials

SNMs are, in contrast, those capable of undergoing sustained fissioning and which can, therefore, be used as reactor fuel or weapons components. They may be plutonium (Pu), uranium 233, or uranium enriched isotopes U–233 or U–235.

Byproduct materials

Byproduct materials are radioactive (except SNM), yielded in or made radioactive by exposure to the radiation incident to the process of producing or using SNM. Further, the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed, any discrete source of radium–226 that is produced, extracted, or converted after extraction are also radioactive. The materials that are processed, produced, extracted, or converted may be for a commercial, medical, or research activity. Any material that has been made radioactive by use of a particle accelerator, or any discrete source of naturally occurring RAM, other than source material, has been determined to pose a threat to the public health and safety. This is similar to the threat posed to the public health and safety by a discrete source of radium–226.

Air Force Radioisotope Committee

The NRC has delegated regulatory authority to the AF for the RAMs in its inventory through the United States Air Force (USAF) Master Materials License (MML). This authority covers items from chemical agent monitors to depleted uranium (DU) munitions. Through the MML, the NRC provides the Air Force Radioisotope Committee (RIC) broad authority and responsibility for permitting RAM use in the AF. While acting essentially as the "Air Force NRC," the RIC ensures the receipt, possession, distribution, use, transfer, and disposal of RAMs are according to the provisions of the MML and applicable federal regulations. This gives the AF greater flexibility in the management of commodities containing RAM. No one may accept RAM into the USAF inventory, including local purchase, without written permission from the RIC. This written permission is typically in the form of a permit.

The Air Force Medical Support Agency Bioenvironmental Engineering (AFMSA/SG3PB) office manages the MML. Functioning out of this office is the RIC secretariat, the administrative arm of the RIC. Every year the NRC conducts a four-day inspection of AFMSA/SG3PB radiation programs to ensure the conditions of the license are satisfied. It is under the authority of this NRC license that AFMSA/SG3PB issues permits.

AF organizations must get a permit before receiving, storing, distributing, using, transferring, or disposing of RAMs. The type of permit needed depends on the kind of RAM that will be used. Permits ensure material control as well as safety and compliance with NRC requirements. The requirements of a permit, such as leak test frequency, inventory, and administrative controls, depend on the scope of the permit. The permit is normally issued to the squadron commander who legally owns the material (called the permittee). A specifically trained individual is requested and designated by the RIC as the permit radiation safety officer (RSO). This is normally the base bioenvironmental engineer (BEE) or senior noncommissioned officer (SNCO). The designated individual is responsible for local consultation, training, and periodic oversight or monitoring of compliance aspects.

The exception to the permit requirements includes those items considered “generally licensed” RAM. These are usually small radioactive sources that are used in instruments or other devices. Even though they do not require a formal permit from the RIC, most of the requirements are the same. AFMSA/SG3PB must still be notified of use and ownership of these devices.

The two different permits issues by AFMSA/SG3PB include template and non-template in accordance with (IAW) Air Force Manual (AFMAN) 40–201, *Radioactive Materials (RAM) Management*.

Template permits

A template, or standardized, permit is used for RAM contained in items or devices that present minimal radiation risk and can be controlled by standardized or template permit conditions. These are the most common AF permits. Template permits cover the following radioactive items:

- Chemical agent alarms, detectors, and monitors.
- X-ray fluorescence devices such as Niton or Science and Technology (SCITEC) Incorporated products.
- Targeting devices such as low-altitude navigation and targeting infrared for night (LANTIRN) pods.

Non-template permits

A non-template permit is used for authorizing RAM uses that do not lend themselves to the use of standard permit conditions either due to the unique nature or relative risk of the material being used. AF organizations that intend to use non-template permitted items or unsealed RAMs must apply for a permit using the NRC Form 313, Application for Materials License. The permit process is initiated by sending a letter to AFMSA/SG3PB. Once they receive the request, a binder containing instructions for providing all necessary application information will be mailed to the permittee. The permittee follows the instructions and returns the completed binder to AFMSA/SG3PB. Examples of non-template permits include, but are not limited to, Troxler gauge permits, medical permits, broad scope permits, academic permits, research and development (R&D) permits, and other permits of a certain risk which warrants control beyond those established in a template permit format.

Permit conditions

The conditions listed in the permit describe the parameters under which the RAM may be legally received, possessed, transferred, stored, used, and disposed. During an inspection, the auditor/inspector will use the permit conditions as the basis for the inspection. The installation RSO is responsible for ensuring that the parameters described in the radiation permit are followed. Any BE journeyman may share in this responsibility; that is why it is important to understand the intent of the "conditions" portion of the permit. The following are a few examples of some enforceable conditions on a typical permit.

- All device labels are affixed at the time of receipt and kept on the device for the life of the device.
- At least every six months, permitted devices must be tested for leakage of RAM and for proper operation of the on-off mechanism and indicator.
- Conduct an inventory every six months.
- Do *not* abandon the RAM possessed under this permit.

BE journeyman will likely be involved with leak testing. Leak testing is an extremely important condition of a permit; the testing process and documentation may be examined in an audit. There are some basic requirements for leak testing summarized by the following:

- Upon RAMs with a half-life of more than 30 days, perform a leak test before being put into use and at least every six months after that. The only exceptions to this rule are tritium, radioactive gases, and sealed sources for nuclear medicine use.
- For beta and/or gamma emitting RAM that is less than 100 µCi, or alpha emitting material that is less than 10 µCi, no leak test is required.
- If not an alpha source, no leak test is required while it's in storage. A leak test must have been completed in the past six months if transferring material to someone else or removing the device from storage for use.
- If the RAM is an alpha-emitter and that is what it is being used for, a leak test must be completed every three months. (Beta or gamma emitters that incidentally leak a small number of alphas are not subject to the three-month test requirement because the RAM is being used as a beta/gamma emitter.)
- Leak test samples are forwarded to the radioanalytical laboratory at the United States Air Force School of Aerospace Medicine (USAFSAM). If a leak test reveals the presence of 0.005 µCi of removable contamination, appropriate corrective actions must be taken, as outlined in AFMAN 40–201.

Recordkeeping

Each permit must have its own binder. Records and reports required by the NRC and AF regulations that apply to each permit (including the permit and permit application), permit amendments, and all correspondence related to the permit must be kept in this binder, commonly referred to as a "permit binder." The contents of the permit binder must include the items described in the following table.

Permit Binder Contents	
Documents	**Description**
Chronology	A chronology of leak test swipes, calls made, and so forth, with dates.

Permit Binder Contents	
Documents	**Description**
Permit	- The actual permit. - Any requests for change (memos). - Additional requirements (e.g., "tie-downs"). - Sealed source model number and NRC device registry number (if available). - A copy of the permit application.
RSO Appointment Letters	These must be included when the commander appoints a permit RSO. It is considered advisable to have at least one workplace RSO appointed by the commander upon recommendation of the permit RSO.
Training Documentation	Signed AF Form 2767, Occupational Health Training and Protective Equipment Fit Testing (LRA), showing all required training on the source for affected base personnel.
Inventories	An inventory of all sealed sources must be conducted IAW the permit. The inventory sheet must list: Inventory date. Model number and serial number of each source or device. Radionuclide and its activity. Location of each source or device. Signature of the permit RSO certifying the inventory accuracy.
Facility/Area Surveys	Picture of room, radiation levels, and associated calculations needed to assess personnel exposure levels.
Leak Test Swipes	Record of swipes for all permitted radioactive items. Chemical agent monitors must be swiped yearly; all others must be swiped every six months. These records must have the RSO's signature and date.
Shipping	The recipient's current permit must be on hand prior to shipping any radioactive item. Further, shipping records and confirmation of receipt must also be available.
Equipment Maintenance	Instrument calibration records and repair records.
Inspection, Reviews, IG Reports, NRC Reports	Documentation of internal inspections and all other inspections.
References	Meetings, memos, directives.

An NRC inspector or an inspector from the Air Force Inspection Agency (AFIA) can make no-notice inspections of permit compliance. In such instances, wing leadership must be briefed and the RSO will accompany and assist the inspector. The inspector will look for compliance with permit requirements and/or may assess any contractors doing work using RAMs on the installation. Always ensuring permit requirements are met, as well as maintaining well-organized files with all required documentation related to the permit, helps make the inspection go smoothly. Monitoring permit programs as previously described above may be tedious but is an important aspect of the ability to assist the wing mission. Doing poorly on such an inspection requires corrective action at the least; however, it may also impact the mission by losing the authorization to use the resource that contains RAM.

Familiarity with AFMAN 40–201 is critical for proper management of RAM. It contains additional program requirements that help ensure control of RAM, training requirements, procedures for inspections, and emergency requirements. In addition to permit compliance, the AFIA inspector may assess the overall radiation safety protection program as described in the AFMAN.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

622. Radioactive decay

1. What can changes in the number, arrangement, or energy of nucleons cause?

2. What happens during the process of radioactive decay?

3. What is the relatively long-range repulsive electromagnetic force of the proton called?

4. What happens during internal conversion?

5. What is the term for the splitting of a nucleus into at least two other nuclei that release a large amount of energy?

623. How radiation interacts with matter

1. What is excitation?

2. When are alpha particles most dangerous?

3. When is calculating the beta particle range useful?

4. For the purposes of radiation safety protection, how is bremsstrahlung avoided?

5. Why is gamma/X-ray a very serious external hazard?

6. What happens to a photon during pair production?

7. What is another term for the splitting of a nucleus?

624. Radiation and radioisotopes (quantities and units)

1. If an isotope is very unstable, at what rate does it decay?

2. Concerning radioactivity, why is it important to know the amount of Cis?

3. What effect do more transformations (per unit of time) have on the amount of energy that is emitted?

4. What is SA?

5. What is used to determine total exposure and estimated dose?

6. Why is the D a more useful quantity?

7. Although more than one dose equivalent unit exists, which unit of measurement is most likely to be seen?

625. Biological effects of ionizing radiation

1. How does direct damage to a cell occur from exposure to ionizing radiation?

2. What is meant by the term nonstochastic?

3. What do the symptoms of ARS depend upon?

4. What is the most likely outcome of an acute dose of 450 rem?

626. Sources, use, and production of X-rays

1. What can happen if the focusing cup on the X-ray machine does not properly control electrons?

2. If focal spot is small, then what will the image quality of the X-ray be?

3. What is the effect on the patient if an X-ray technician uses a high kVp setting?

4. Why is it important that the interior of the glass envelope surrounding the cathode be kept under a partial vacuum?

627. Radioisotope permit program

1. What types of RAM are covered by template permits?

2. Where is information found describing the parameters under which RAM may be legally received, possessed, transferred, stored, used, and disposed?

3. Who can make a no-notice inspection of permit compliance?

Answers to Self-Test Questions

622

1. An unstable condition.
2. The nucleus emits radiation and transforms the unstable atom into a different nuclide. These materials must go through at least one, and often many steps, throwing off particles or energy.
3. The coulomb (C) force.
4. An electron around the nucleus of a gamma-emitting atom absorbs the excitation energy, resulting in the electron being ejected from the atom.
5. Fission.

623

1. The process that involves not having sufficient energy to remove the electron; rather, it merely jumps to a higher atomic energy level.
2. When they get inside the body.
3. When evaluating hazards from beta particles or evaluating shielding designs.
4. By surrounding the beta emitter(s) with a low atomic number material.
5. Due to its high penetrating ability.
6. A photon disappears in the vicinity of a nucleus and an electron and positron appear in its place.
7. Fission.

624

1. Very fast (within seconds or minutes).
2. The amount of Cis tells you how many atoms are disintegrating in a given period of time.

3. It results in the greater amount of radiation emitted.
4. The number of Ci/g of material.
5. Exposure rate (R/hr or mR/hr) and the period of exposure.
6. Because it is applicable to any type of absorbing media and any type of ionizing radiation.
7. The rem.

625

1. Radiation collides with or passes close enough to a molecule in the DNA to cause it to break apart.
2. It refers to deterministic with effects characterized by three qualities.
   (1) A certain minimum dose must be exceeded before the particular effect is observed.
   (2) The magnitude of the effect increases with the size of the dose.
   (3) There is a clear, unambiguous causal relationship between exposure to the agent and the observed effect.
3. The dose received over a person's whole body.
4. 50% of untreated exposed people are expected to die within 60 days after exposure.

626

1. The electrons could spread out and many of them could miss the target, resulting in unnecessary radiation exposures.
2. Its image will be sharper.
3. This setting produces more penetrating X-rays, which reduces a patient's exposure.
4. It minimizes interactions with air molecules and helps slow down the eventual burnout of the tube.

627

1. Chemical agent alarms, detectors, and monitors; X-ray fluorescence devices such as Niton or SCITEC products; and targeting devices such as LANTIRN pods.
2. The "conditions" section of the permit.
3. An NRC inspector or an inspector from the AFIA.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (622) What is another name for the electromagnetic force that causes protons to tear apart the nucleus of the atom during the process of radioactive decay?
a. Coulomb (C).
b. Positron.
c. Isomeric.
d. Transformation.

2. (622) Which statement *best* describes an alpha particle?
a. Heavy and slow.
b. Light and slow.
c. Heavy and fast.
d. Light and fast.

3. (622) Which particle is considered the *most* ionizing?
a. Positron.
b. Electron.
c. Alpha.
d. Beta.

4. (622) In beta plus (β^+) decay, the parent nucleus changes a
a. proton into a neutron and gives off a positively charged particle.
b. neutron into a proton and gives off a positively charged particle.
c. proton into a neutron and gives off a negatively charged particle.
d. neutron into a proton and gives off a negatively charged particle.

5. (622) What can be used to classify a neutron?
a. Size.
b. Heat.
c. Speed.
d. Weight.

6. (623) What is the process by which an alpha particle gains kinetic energy?
a. Ionization.
b. Excitation.
c. Bremsstrahlung.
d. Compton scattering.

7. (623) The linear energy transfer (LET) of a beta particle is lower than that of an alpha particle because of its
a. larger mass and higher speed.
b. larger mass and slower speed.

c. smaller mass and higher speed.
d. smaller mass and slower speed.

8. (623) In pair production, a photon disappears with an electron and positron appearing in its place, and the energy left over from the transformation is
a. transferred *only* to the positron.
b. transferred *only* to the electron.
c. absorbed by the nucleus.
d. shared by the particles.

9. (624) Since every isotope decays at a specific rate, the rate of decay (λ) is proportional to the
a. dose equivalent (H).
b. stability of the nucleus.
c. radiation absorbed dose.
d. concentration of radioactivity.

10. (624) Which type of ionizing radiation has been found more effective in producing cataracts?
a. Beta.
b. Alpha.
c. X-Rays.
d. Neutrons.

11. (624) When comparing the relative toxicity of various radiations, what is the result of a higher rate of linear energy transfer (LET)?
a. Less effective in producing biological damage.
b. More effective in producing biological damage.
c. Less effective in reducing how much energy was absorbed.
d. More effective in reducing how much energy was absorbed.

12. (625) Cells that form which type of tissues are most easily damaged by ionizing radiation?
a. Stem.
b. Somatic.
c. Lactotrope.
d. Reproductive.

13. (625) What types of cells from forming tissue are *most* easily damaged by ionizing radiation?
a. Bone.
b. Blood.
c. Nerve.
d. Muscle.

14. (625) Most biological effects of ionizing radiation that can be directly observed are of which type?
a. Random.

b. Stochastic.
c. Probabilistic.
d. Deterministic.

15. (625) Regarding acute radiation syndrome (ARS), what is the correct order of the body areas damaged as the dose increases?
a. Hematopoietic, gastrointestinal (GI), pulmonary, and central nervous system.
b. Central nervous system (CNS), pulmonary, GI, and hematopoietic.
c. Pulmonary, hematopoietic, GI, and central nervous system.
d. GI, central nervous system, pulmonary, and hematopoietic.

16. (626) Which component of an X-ray tube is negatively charged?
a. Anode.
b. Cathode.
c. Tube head.
d. Collimator.

17. (626) What term is used to identify the area of the target bombarded by electrons at any moment in time in an X-ray machine?
a. Field.
b. Parameter.
c. Focal spot.
d. Total distance.

18. (626) What role does the collimator play in X-ray production?
a. Reduces scatter radiation.
b. Filters out lower energy photons.
c. Slows down the eventual burnout of the tube head.
d. Increases the number of electrons fired from the filament.

19. (627) Within the radioisotope permit program, which of the following *is not* a type of material that the Nuclear Regulatory Commission (NRC) regulates?
a. Source.
b. Byproduct.
c. Radiological.
d. Special nuclear.

20. (627) Who has the broad responsibility of ensuring the receipt, possession, distribution, use, transfer, and disposal of radioactive materials (RAM) within the Air Force?
a. Radiation Commission.
b. Nuclear Regulatory Commission (NRC).
c. Air Force Radioisotope Committee (RIC).
d. United States Air Force Master Materials License (MML).

21. (627) Under which radiation permit would an X-ray fluorescence device be covered?
a. Template.
b. Traditional.
c. Non-template.

d. Nontraditional.

22. (627) A research and development (R&D) permit is an example of which type of radiation permit?
a. Nontraditional.
b. Non-template.
c. Traditional.
d. Template.

23. (627) Who is responsible for ensuring the parameters described within each radiation permit are followed?
a. Shop supervisor.
b. Permit control officer.
c. Radiation safety officer (RSO).
d. Bioenvironmental engineer (BEE).

Please read the unit menu for unit 2 and continue ➔

Student Notes

Unit 2. Ionizing Radiation Detection

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SINCE THE PRESENCE of ionizing radiation cannot normally be detected by the five senses, humans have capitalized on technology to develop increasingly accurate radiation assessment equipment. This is essential to the detection and measurement of different types of potentially hazardous ionizing radiation. One of the main responsibilities for BE technicians is learning to use ionizing radiation detection equipment. This will facilitate both personnel and other people who live and work on the installation safe from being exposed to dangerous levels of ionizing radiation.

628. Bioenvironmental engineering role in the USAF Personnel Dosimetry Program

Any person who routinely works with RAMs or ionizing radiation-producing equipment can potentially receive an occupational exposure to ionizing radiation. An effective radiation safety program includes the monitoring of these exposures. The USAF *Personnel Ionizing Radiation Dosimetry Program* (hereafter referred to as the *dosimetry program*) establishes procedures and services to ensure the issuance, wearing, and monitoring of ionizing radiation detection devices. Dosimeters are issued to and worn by personnel occupationally exposed to ionizing radiation who are likely to exceed an external dose of 1 millisievert (mSv), which is 100 millirem (mrem), or 2 percent (%) of annual limits of intake (ALI). BE is responsible for conducting the dosimetry program and a BE journeyman is typically given the responsibility of managing this program. The following paragraphs discuss the critical role BE journeymen play in keeping radiation workers safe and healthy.

AFMAN 48-148, *Ionizing Radiation Protection*, and AFMAN 48–125, *Personnel Ionizing Radiation Dosimetry*, comprehensively list BE's dosimetry program responsibilities. Some of the significant responsibilities include 1) conducting the base level dosimetry program, 2) enrolling personnel into the dosimetry program, 3) determining the type of external monitoring required, reporting and investigating abnormal exposures and overexposures, and 4) maintaining and reviewing ionizing radiation exposure monthly, quarterly, and annual dosimetry reports (received from the USAF Radiation Dosimetry Laboratory [RDL]).

A key responsibility of the installation radiation safety officer (IRSO) is to maintain ALARA radiation exposures to personnel. The dosimetry program directly supports the ALARA concept by ensuring workers' radiation exposures are monitored; allowing alteration of duties or procedures before limits are exceeded. The success of the dosimetry program will depend, to a large degree, on interactions with individuals and organizations on and off base. Some of the key responsibilities are discussed in the following paragraphs.

If an abnormal exposure occurs, the IRSO determines the appropriate team to conduct an investigation for determining the cause(s). The investigation will include interviewing the workplace supervisor and enrolled individual.

Abnormal exposure

An abnormal exposure is defined as one that, if continued at the same rate, would result in an exposure greater than the annual allowable dose. At the conclusion of the investigation, it may be necessary to provide training and recommendations on the proper wear, handling, and storage of dosimeters. The IRSO has certain responsibilities as outlined in AFMAN 48–125 that require notifying the major command (MAJCOM) BE, USAF RDL, and AFMSA/SG3PB of any abnormal or potential overexposures.

Overexposure

An overexposure occurs when an individual exceeds their allowable dose. The annual allowable dose limits are specified in Title 10 CFR, Part 20, *Standards for Protection Against Radiation*.

Interaction will also be required with the public health (PH) flight to inform them of the scope of the radiation hazard(s) and any recommended duty limitations for pregnant workers assigned to Air Force specialty codes (AFSC) where there are exposures to ionizing radiation.

The manager of the dosimetry program interacts with the USAF RDL to request priority processing for dosimeters issued to pregnant workers, or used in planning special exposures, receiving exposure listings, and coordinating on abnormal or overexposures.

Along with knowledge of the dosimetry program responsibilities, it is also important to know the types of dosimeters, how each is used/worn, and the types of radiation measured.

629. Types of personal dosimeters

Although the overall goal of assessing radiation exposure is the same for all dosimeters, each dosimeter type monitors a specific part of the body and has specific instructions for wearing. All approved radiation dosimeters are listed in AFMAN 48–125; dosimeters other than the models listed in AFMAN 48–125 must be approved by USAFSAM prior to use.

Whole-body dosimeter

This general-purpose dosimeter is used to measure ionizing radiation exposures to a person’s whole body (fig. 2–1). The whole-body thermoluminescent dosimeter (TLD) is sensitive to beta, gamma, and X-ray radiation, and must be worn by all personnel enrolled in the dosimetry program regardless of other type(s) of dosimeters worn. If specialty dosimeters such as collar or extremity dosimeters are not worn, the whole-body dosimeter will also be used to determine the dose equivalents for the head, lens of the eye, and extremities. This dosimeter is attached to the outer clothing on the front torso below the shoulders and above the hips. When worn with a collar dosimeter, the whole-body dosimeter is always worn underneath any lead apron. When worn WITHOUT a collar dosimeter and a lead apron is worn, the whole-body dosimeter is worn on the individual’s collar, outside any protective shielding. When a whole-body dosimeter is not being worn, it must be stored with the area control dosimeter.

Figure 2–1. Proper position of whole body dosimeter.

Area control dosimeters

Area control dosimeters are used to measure background radiation accumulated during transit and storage of dosimeters. The USAF RDL provides area control dosimeters with each issue. Like dosimeters used for monitoring worker exposures, control dosimeters are exchanged and returned to the USAF RDL for processing.

Each area monitored must have one control dosimeter for each dosimeter type used within the area (e.g., one whole-body dosimeter, one neutron dosimeter, one extremity dosimeter, etc.). For example, medical radiology technicians are typically required to wear whole-body dosimeters and extremity dosimeters to properly monitor radiation exposures. In this case, two control dosimeters would be required; that is, one whole-body and one extremity dosimeter. In contrast, NDI technicians typically require only a whole-body dosimeter. In this case, since only one type of dosimeter is used, only one control dosimeter would be needed—a whole-body dosimeter. Area control dosimeters are always kept in the same designated storage area where personal dosimeters issued to workers are stored when they are not being worn. Area control dosimeters must never be used for individual monitoring.

Collar dosimeter

A collar dosimeter (fig. 2–2) is the primary device used to evaluate exposures to the head and lens of the eye. When applicable, a collar dosimeter is used to facilitate calculating the effective dose equivalent under special monitoring circumstances as outlined in AFMAN 48–125. Consideration for wearing this dosimeter should be given to individuals performing fluoroscopic examinations, operating portable medical X-ray equipment, performing cardiac catheterizations, or who otherwise may wear protective lead aprons. Consideration should further be given when the whole-body dosimeter may not provide an accurate assessment of doses to the head, neck, or lens of the eye. The collar dosimeter is always worn outside any shielded protective covering and as near to the thyroid as possible to determine the unshielded exposure to the head and lens of the eye. When a collar dosimeter is not being worn, it must be stored with the area control dosimeter.

Figure 2–2. Proper position for collar dosimeter.

Extremity dosimeter

The extremity dosimeter (fig. 2–3) is the primary device to evaluate exposures to the hand and forearm of an individual; further, it is never worn without a whole-body dosimeter. The dosimeter should be worn on the finger that will receive the highest dose of radiation from the source and must be oriented so that the circular indentation is facing the radiation source. If the extremity dosimeter is worn with lead gloves, it is worn under the shielded lead gloves. When an extremity dosimeter is not being worn, it must be stored with the area control dosimeters.

Figure 2–3. Example of extremity (finger) dosimeter.

Neutron dosimeter

A neutron dosimeter (fig. 2–4) is the primary device for determining the neutron equivalent doses to the whole body. The neutron dosimeter is distinguished from regular TLDs by the amber color casing. It must be worn in conjunction with a whole-body dosimeter, flat against the body, at the mid-section of the individual, with the back of the dosimeter next to the body.

Figure 2–4. Example of neutron dosimeter.

Electronic personal dosimeter

The electronic personal dosimeter (EPD) is an electronic pocket-type dosimeter that is used to detect and monitor radiation exposures to personnel who may encounter gamma, beta, X-ray, and neutron radiation. Radiation detection is accomplished using multiple electronic diodes that are sensitive to different types of radiation.

The use of EPDs is reserved for special circumstances, like emergency response, and selected AF specialties. The USAF RDL recommends EPDs as supplemental dosimetry to be used in conjunction with TLDs. The Mk2 and the N2 are the two types of EPDs.

A stockpile of contingency EPDs maintained by the dosimetry program can potentially be assigned and shipped to AF installations requiring surge support during a radiological response operation.

Capabilities

The EPD detects, monitors, and records personal exposures to ionizing radiation. Internal audible and visual alarm settings (dose, dose rate, count-down time, read time, and failure modes) and digital front panel readings allow the user to be aware of radiation exposure amounts at all times. The EPD can also be used as an area monitor for different types of surveys, such as NDI X-ray surveys. EPDs are sensitive to temperature and humidity; they do not operate correctly in temperatures over 105 degrees (°) Fahrenheit (F), or humidity less than 20% or more than 90%.

Mk2

The Mk2 (fig. 2–5) is an electronic dosimeter that detects and measures beta and gamma radiation; it does not detect alpha or neutron radiation and will not accurately measure radiation produced from digital pulse X-ray machines.

Figure 2–5. Mk2 electronic personal dosimeter.

N2

The N2 (fig. 2–6) is designed to detect, monitor, and record gamma, X-ray, and neutron radiation dose equivalent to the wearer (i.e., radiation workers, medical staff, medical patients, emergency response personnel, etc.) who might have to perform duties in an area where a gamma and/or neutron radiation field exists.

Figure 2–6. N2 electronic personal dosimeter.

Calibration

EPDs used for first responder or readiness purposes require annual calibration. EPDs used for personnel monitoring on a regular basis require a six-month calibration cycle. Calibration is accomplished by the USAFSAM RDL.

Operation

In order to provide consistently accurate results, proper EPD operation is essential. Capabilities and methods of operation differ between dosimeters as previously exhibited. Basic operational considerations are explained in the paragraphs to follow. For additional instruction, refer to the manufacturer's operations manual for the specific device.

Mk2

The Mk2 can be used for routine operations to monitor real-time ionizing radiation exposures or used in emergency or disaster response situations where the presence of ionizing radiation is unknown. For most operating conditions, the Mk2 should be worn on the front torso area, outside of any personal protective equipment (PPE) with the orange beta window facing outwards. **Note:** *Never* cover this part of the EPD. By wearing the Mk2 on the exterior of PPE, the user can read the liquid crystal display (LCD), see the visual alarm light emitting diode (LED), and operate the push-button. The Mk2 can be placed inside a clear, sealable plastic bag to minimize/prevent contamination of the unit; however, this affects the measured dose for beta radiation.

N2

The N2 should be worn under the direction of the health and safety professional. N2s are currently used by weapons of mass destruction (WMD) first responders exclusively. For most operating conditions, the N2 should be worn on the outside of any PPE (on torso close to the body) with the push-button control facing outwards. By wearing the N2 on the exterior of PPE, the user can read the N2 LCD display and operate the push-button. It should be worn in a manner that prevents it from swinging freely away from the body. It can be placed in a plastic bag to prevent contamination of the N2; this will not affect the neutron dose readings in any way.

EasyEPD2 computer program

The EasyEPD2 computer program is used to program EPDs prior to use. It allows the user to read and write data and set parameters by using an infrared (IR) communications cable. The EPD dose should be set to zero before issue. Each EPD should be issued to an individual user unless they are being used as area monitors. After use, EPD monitoring data should be downloaded to record dose and dose rate. This information should be recorded in the individual's medical records and sent to the USAFSAM RDL to be added to dosimetry records if a TLD was not worn.

630. Enrolling and disenrolling personnel

The success of the base's dosimetry program depends, to a large degree, on how the dosimeter monitor manages each aspect/process of the program. Enrolling, disenrolling, exchanging, and shipping dosimeters are extremely important parts of the base's dosimetry program. Each of these processes must be properly conducted to ensure personnel working with ionizing radiation producing sources are adequately monitored and their exposure levels are properly monitored and recorded.

Enrolling persons in the dosimetry program

Any workers whose job description includes duties for exposure likely to exceed 10% of the annual external dose limit or 10% of the ALI must be enrolled. The USAF RDL is available to provide consultative assistance in determining whether monitoring is appropriate. It is important to remember that the decision to enroll individuals in the dosimetry monitoring program is made by the IRSO. The following are the steps to enroll an individual in the dosimetry program.

1. Coordinate enrollment information with the USAF RDL.
2. Establish the exposure history.
3. Brief the wearer on topics specified in AFMAN 48–125.
4. Complete the RDL Listing 1523, Dosimetry Assignment Data.
5. Issue the dosimeter.

If the individual has had previous exposure and the exposure was during an assignment to another AF installation, request an USAFSAM Form 1527–2, Cumulative Occupational Exposure History to Ionizing Radiation, from the USAF RDL. If the exposure was a result of civilian employment, request an NRC Form 4, Cumulative Occupational Dose History (or equivalent), from the individual's employer prior to allowing the person to work in a radiation area.

Inform the individual that if they are employed off-duty where they are exposed to ionizing radiation, they must provide an NRC Form 5, Occupational Dose Record for a Monitoring Period (or equivalent), for each monitoring period of employment. The IRSO forwards this information to the USAF Radiation Dosimetry Laboratory. Once exposure history has been established, enroll the individual in the Dosimetry program.

To add the individual to the base radiation dosimetry program, fill out all areas of RDL Listing 1523. If the individual is a one-time user (visitor, student, special study, etc.), annotate as "one time" in the remarks column of Listing 1523. When the individual requires multiple badges, it is only necessary to provide the information above once for subsequent dosimeters.

Per AFMAN 48–125, persons enrolling in the dosimetry program must be briefed on proper wear and storage of their dosimeter; hazards associated with ionizing radiation; methods to keep exposures ALARA; and if female, their responsibility to report to public health as soon as possible following pregnancy confirmation.

The USAF RDL has a secure web site to make changes to an individual's information registered in the dosimetry program. The secure site is a web-based application used to track dosimeters, specifically TLDs, worn by military members working in areas where radiation exposure may occur.

The Radiation Dosimetry Web (RadDos) secure web site records who is assigned the TLD, the monitoring period, and any exposure during the monitored time period.

Complete a personnel information change form for each individual being added to the base radiation dosimetry program using the secure web site. To register a foreign national into the dosimetry program, use the checklist provided in AFMAN 48–125.

Procedures for disenrolling persons from the dosimetry program

At most AF bases, individuals enrolled in the dosimetry program should out-process through the BE flight. If an individual enrolled in the program leaves without proper notification, his/her supervisor will have to return the dosimeter and cooperate in the assessment of an assigned administrative dose. Use the following steps to disenroll an individual from the dosimetry program.

1. Determine if the individual wore the dosimeter during the monitoring period. If so, write “delete” in the remarks column on the RDL Listing 1523; if not, write “delete” and “not worn” in the remarks column on the RDL Listing 1523.
2. Complete the personnel information change form using the RadDos secure web site, or send a message to the USAF RDL with the following information: base code, name of the monitored individual to be deleted, social security account number ([SSAN] – as printed on RDL Listing 1523), and base area.
3. Submit all dosimeters for individual(s) deleted from the program to the USAF RDL at the end of the monitoring period.

631. Exchanging and shipping dosimeters

Dosimeters are exchanged either monthly or quarterly. Most occupational radiation exposure circumstances encountered within the USAF can be adequately monitored by using dosimeters exchanged on a quarterly basis. Using quarterly monitoring periods generally provides optimum accuracy for low dose rate environments. Factors necessitating more frequent exchange (monthly) might include the prior exposure history in the unit for individuals performing similar duties, prior exposure history of the individual beginning work as an occupational radiation worker, the potential for accumulating radiation doses at a high or irregular rate. Additional factors include training of individuals, occupational radiation workers who are pregnant and have the potential to exceed 5 mSv (500 mrem) during their pregnancy, and certain operations having an exceptionally high radiation exposure potential greater than 12.5 mSv (1.25 rem) per quarter.

Exchanging dosimeters

Use the following steps when exchanging dosimeters:

1. Inspect the shipment of dosimeters for the upcoming monitoring period.
2. Assemble the dosimeters for the upcoming monitoring period.
3. Exchange the dosimeters.

Before exchanging dosimeters, assemble the dosimeters for the upcoming monitoring period. Do this by matching each identification label (provided by the USAF RDL) with each TLD holder and hanger as recorded on the RDL Listing 1523. If it is necessary to make any changes to this label, the original print must remain legible to properly account for the card and dosimeter. Then remove the TLDs from the shipping tray and place each into the properly labeled hanger.

All dosimeters must be exchanged, including the control badge, within two workdays of the end of the monitoring period. Provide the dosimeters to the area monitor with instructions to not open dosimeters, to exchange them one-for-one, and to submit any dosimeter with suspected high exposures immediately for analysis. Dosimeters should be exchanged one-for-one; that is, do not take a dosimeter without having one to leave in its place and do not leave a dosimeter without having one to take. If any dosimeters are lost or not returned, notify the IRSO and annotate the RDL Listing 1523.

Exchanging dosimeters is a perfect time to observe and confirm that workers are using and storing dosimeters properly. Proper wear and storage of dosimeters is essential for accurate accounting of radiation exposures. When not in use, dosimeters must be stored with the area control badge in an area within the work area that is approved by the IRSO.

Shipping dosimeters

Use the following steps when shipping dosimeters back to the USAF RDL:

1. Account for all dosimeters.
2. Disassemble dosimeters.
3. Repack dosimeters.
4. Coordinate shipment with the shipping agency.

Once collected, disassemble the dosimeters and crosscheck the RDL Listing 1523. The TLD number must be compared to the RDL Listing 1523 to account for *all* issued dosimeters. Make sure the listing reflects all additions, deletions, and changes. “Lost” or “Not Returned” entries must be made on the listing as applicable. Remove the identification labels from the hangers and discard making sure any Privacy Act information is protected IAW Air Force Instruction (AFI) 33–322, *Records Management and Information Governance Program*.

Place the TLD holders in the original shipping tray. Pack any extremity dosimeters in a separate container. Seal all dosimeters and the original RDL Listing 1523 in the shipping container that was retained at the beginning of the monitoring period. Secure the package with reinforced tape, taking care to completely seal all edges. Attach one “CAUTION” label and the address label to the package and ship by the most expeditious and traceable means back to the USAF RDL.

The dosimeters must be shipped within five workdays after the monitoring period ends. If the package is shipped through the packing and crating section of the logistics readiness squadron, a Department of Defense (DD) Form 1149, Requisition and Invoice/Shipping Document, needs to be used. A letter justifying the shipping method may be needed. The package may also be able to ship through the commander’s support staff office.

632. Dosimetry results and histories of occupational exposure to ionizing radiation

Federal and Department of Defense (DOD) statutes require the AF to report radiation doses. To meet this requirement, the USAF RDL will produce and forward to each base exposure reports for all personnel enrolled in the dosimetry program.

Varying ionizing radiation energy

Ionizing radiation can have varied amounts of energy, some penetrate deeper than others, and some organs are more susceptible to the damaging effects of ionizing radiation. Reports of personnel dosimetry results include equivalent doses for various susceptible parts of the body and at various depths of penetration into the body. Reports can include some or all of the radiation dose values provided in the following paragraphs.

Eye dose equivalent

The external dose equivalent to the eye lens is assessed at a tissue depth equivalent to the approximate thickness of the cornea and aqueous humor. This total value must not exceed 37.5 mSv (3.75 rem) per quarter or 150 mSv (15 rem) in one year.

Head dose equivalent

The external dose equivalent to the head, neck, and thyroid is assessed at a tissue depth sufficient to reach deep tissue and blood forming organs. This total value must not exceed 12.5 mSv (1.25 rem) per quarter or 50 mSv (5 rem) in one year.

Extremity dose equivalent

The external dose equivalent to the extremities (hands and forearms) is assessed at a tissue depth equivalent to the dead layer of skin. This total value must not exceed 125 mSv (12.5 rem) per quarter or 500 mSv (50 rem) in one year.

Shallow dose equivalent (skin)

The external dose equivalent to the skin of the whole body is assessed at a tissue depth equivalent to the dead layer of skin. This total value must not exceed 125 mSv (12.5 rem) per quarter or 500 mSv (50 rem) in one year.

Deep dose equivalent (whole body)

The external dose equivalent from whole-body exposure is sufficient to reach deep tissue and blood forming organs such as bone marrow. Deep dose equivalent to a pregnant worker must not exceed 5 mSv (0.5 rem) for the duration of the pregnancy.

Committed effective dose equivalent

The committed effective dose equivalent (CEDE) to organs and tissues is received from an intake of RAM. CEDE applies specifically to the dosimetry of internally deposited radionuclides. The CEDE must not exceed 50 mSv (5 rem) in one year.

Total effective dose equivalent

The total effective dose equivalent (TEDE) is the sum of the deep dose equivalent (for external exposures) and CEDE (for internal exposures) from all sources for the monitoring period indicated. TEDE does not apply to dose attributed to eye dose equivalent, extremity dose equivalent, or shallow dose equivalent. TEDE must not exceed 12.5 mSv (1.25 rem) per quarter or 50 mSv (5 rem) in one year.

Radiation dosimetry listings and forms

RDL Listing 1499–1, Occupational Radiation Exposure Report

The USAF RDL prepares and issues the RDL Listing 1499–1 for each monitoring period (monthly or quarterly) within 30 days following the monitoring period or upon written request. The listing reports the external and internal dose equivalent results for all individuals assigned to a given base code and area for the respective monitoring period and total effective and organ dose equivalents for the current calendar year. Once the report is received (from the Radiation Dosimetry Web secure web site) it must be reviewed, compared to established dose limits, and signed by the IRSO indicating the review has taken place and their concurrence with the data on the listing. A copy of the signed listing is provided to the workplace supervisor.

RDL Listing 1499–2, Occupational Exposure Report (Summary)

This report is similar to the RDL Listing 1499–1, except that the listing includes exposure data from the beginning of the calendar year to the date the report is prepared.

USAFSAM Form 1527–1, Annual Report of Individual Occupational Exposure to Ionizing Radiation

The USAF RDL prepares a separate listing of this report once per calendar year for each individual registered in the program during the previous calendar year. It summarizes internal and external doses received during the year to include results of all AF-provided monitoring and all non-AF monitoring reports submitted to the USAF RDL for entry to the Master Radiation Exposure Registry. The IRSO can access the form using the Radiation Dosimetry Web secure web site. Once the form is received, the IRSO reviews the data, compares it with established dose limits, and distributes the reports to the individuals monitored.

USAFSAM Form 1527–2, Cumulative Occupation Exposure History to Ionizing Radiation

This form is similar to AF Form 1527–1 except that it includes all exposure histories for each monitoring period since an individual was first registering into the Dosimetry Program, including other sources of exposures external to AF practices. Using the Radiation Dosimetry Web secure web site, the IRSO can generate this form. Otherwise, this form is generated by the USAF RDL upon written request of the individual, IRSO, or other authorized organizations and individuals. All requests other than those made for official AF use must have a release signed by the individual for whom the report is requested. The USAF RDL will also provide the listing prior to and following planned special exposures.

Evaluating dosimetry listings

The IRSO must review the dosimetry reports to ensure all exposures are below established dose limits. In many cases, the dosimetry program manager will also review the report findings with the IRSO. Categories of dose limits are as follows:

Potential overexposure

Any dosimeter result that exceeds the applicable dose limits specified in Title 10 CFR Part 20 shall be considered to represent a potential overexposure. Individuals that have possibly received an overexposure will be removed from duties involving radiation exposure pending completion of the final investigation.

Abnormal exposure

Any dosimeter or bioassay result exceeding monthly or quarterly exposure values published in AFMAN 48–125 is considered an abnormal exposure, which is an exposure received in any monitoring period that may be acceptable for that period. However, it would exceed the annual exposure limits if exposure continued at the same rate. The IRSO must initiate a formal investigation for abnormal exposures and take corrective actions as necessary to avoid exceeding annual occupational exposure limits. The IRSO investigates abnormal exposures in the same manner as potential overexposures.

Investigation action level

Investigation action levels are an important part of an effective ALARA program. An investigation action level is a value set by the IRSO that requires further investigation when exceeded. Investigation action levels trigger an investigation when there is an unusual fluctuation from historic dosimetry trends for a given monitored area or section. Radioactivity exceeding the investigation action level may indicate a potential problem that could lead to an abnormal exposure. Levels are normally tailored to each section using the historical dosimetry data for the respective section. In general, the IRSO should develop investigation action levels for each dose equivalent category on the RDL Listings 1499 for individual reporting periods and the annual report.

If any limits are exceeded, it must be brought to the attention of the IRSO for investigation as to why a limit has been exceeded. Investigation procedures for suspected or actual overexposures are outlined in AFMAN 48–125 and are discussed later in this unit.

633. Radiation detection equipment

Ionizing radiation cannot be detected by human sensory organs. Consequently, instrumentation is relied upon for detection and measurement of ionizing radiation. Radiation-measuring devices take advantage of interactions with matter to measure the amount of radiation present. Remember, ionizing radiation causes the release of free electrons and enables current flow. This current flow can be measured and interpreted as an electrical signal on an instrument. Even minute amounts of current can be amplified to create a useful instrument response.

A survey instrument has two basic components: a meter, which provides the display, and the detector. Many survey instruments connect the meter to a separate hand-held detector (probe) via a cable. An advantage to such an instrument is that a single meter can be used with different types of probes; allowing it to measure various types of radiation. Other survey instruments will combine the meter and detector into a single unit; most ion chambers fall into this category. These “single unit” instruments operate as a rate meter and/or scaler.

- Rate meter—typically used when scanning for contamination and when measuring exposure rates (mR) and dose equivalent rates millirem per hour (mrem/hr). A needle moves across a scale that reads in units.
- Scaler—almost all measurements of alpha contamination and most measurements of beta contamination are made using a scaler. A scaler performs a count over a period of time selected by the user and will display the result digitally. They are normally used to measure surface contamination when it is necessary to measure very low levels.

There are several common detection methods used in ionizing radiation detection instruments. These include *scintillation* (used in a number of alpha, beta, and gamma instruments), *neutron detection*, and *gas ionization* (the primary means of detecting beta and gamma radiation).

Scintillation instruments

Radiation passing through certain materials causes *excitation* and *ionization*, which result in tiny flashes of light when atoms return to their ground state. This flash of light is referred to as scintillation and the material that produces this flash of light is referred to as a scintillator.

Each radiation interaction in the scintillator produces one flash of light. In some instruments, the greater the radiation energy transferred to the detector, the brighter the flash of light. These flashes can be collected and counted to obtain a measure of the radiation intensity. A device called a *photomultiplier tube* (PMT) is used to convert each scintillator into an electronic pulse. The internal circuitry converts the pulses into a reading on the meter screen. The ADM–300 alpha X-ray probes (XP), and the SAM 940 are scintillation detectors.

The PMT in these instruments is fragile and therefore must be treated with great care. Another common problem with scintillator instruments is that they employ thin Mylar windows that are susceptible to light leaks caused by small holes in the window material. Since these holes can be too small to see, the detector needs to be checked out prior to use by holding the probe up to a light source and checking the readings. Extreme care must also be taken during use as the Mylar is thin enough to be punctured very easily; the Mylar in the window of the ADM–300 alpha probe (AP) has been known to get punctured just by getting too close to thick grass. Moisture and humidity can also be problematic when using scintillation detectors.

Neutron detection

The detection of neutrons is complicated by the fact that neutrons do not cause direct ionization, and the various materials used for their detection respond differently to different energies. Detectors must be designed to take advantage of the directly ionizing particles that are emitted when neutrons react with certain materials.

The most common instruments used for neutron measurements employ boron trifluoride (BF_3) gas. The neutrons are absorbed by the boron atoms, each of which decay into two charged particles (lithium and an alpha particle). The alpha particle then travels through the gas to produce a pulse. It is usually desirable that the neutron detector read out in units of dose equivalent rate mrem/hr. Such instruments are often referred to as *rem meters*. Two common rem meters used in the nuclear industry are known as *snoopy* and the *rem ball* (fig. 2–7). Unfortunately, the design features that permit the detectors to measure the dose equivalent rate also result in a very heavy instrument (not something that can be carried around for long). Other disadvantages of these instruments include the fact that they are slow to respond and can be difficult to calibrate, since neutron sources of sufficient intensity are not practical.

Figure 2–7. Neutron detector (Ludlum Model 12–4—REM Ball).

Gas ionization instruments

This method of detection is based on the principle of collecting ions formed by the interaction of ionizing radiation with a gas enclosed in a chamber. The gases normally used are air; tissue equivalent gases (those which react to radiation exposure similarly to human tissue such as methane, carbon dioxide, and nitrogen); inert gases (such as argon); and sometimes organic compounds. The detector itself is a gas-filled chamber, which contains a positive anode and a negative cathode. Radiation interacts with the gas and produces ion pairs that are collected at the anode and the cathode. This produces a current and is turned into a reading that is shown on the screen of the instrument or meter. There are three major types of gas instruments: ionization chambers, proportional counters, and Geiger-Mueller (GM) detectors.

Ionization chambers

Although most ionization chamber instruments used in the AF measure induced current, it is easier to visualize the theory of operation by referring to pulse height or pulse size. Alpha, naturally, produces more ions than beta does and thus creates a larger pulse. The same is true of the larger beta pulses compared to those of gamma. This gives ionization chambers the benefit of being able to distinguish between the different types of radiation. These instruments are also beneficial because they measure dose rate directly (the pulse size is proportional to the ionizing ability of the radiation).

An electronic “discriminator” can be used in the circuitry to prevent an instrument from detecting any pulses below a certain minimum voltage. Their primary application is the measurement of exposure rates due to gamma rays or “hard” X-rays. As the electronic signal from an ion chamber is relatively small, ion chambers are usually used to measure relatively high exposure rates (those above 1 mR/hr). Their major advantage is that they are energy independent; meaning that the accuracy of their measurement is unaffected by the energy of the gamma rays or X-rays.

Proportional counters

Proportional counters are mostly used to count alpha and beta particles rather than gamma rays. Since alpha particles produce larger pulses than beta particles, a proportional counter can be set up to count only alpha particles, only beta particles, or both alpha and beta particles. The most common gas used in these counters contains a mixture of 90% argon and 10% methane. Some proportional counters employ sealed chambers while others operate in the gas flow mode where gas is continually flowing through the chamber of the instrument.

A major advantage of gas flow proportional counters is that they can be constructed with very large and very thin windows; this increases the rate at which they can survey a given area and increases the counting efficiency for low energy beta particles.

GM detectors

GM detectors, gas filled detectors that have a very high voltage, are good for detecting radiation sources and measuring low radiation levels. These detectors cannot distinguish between radiation types, and they are not very accurate. Physical discrimination must be provided for these instruments in the form of shields that can prevent alpha and beta from entering the tube. This discrimination permits only the gamma/X-ray detection of a certain minimum energy.

Calibration/operation

Before discussing how to use some of the radiation detection equipment, it is important to know how to operate and calibrate the equipment. One of the keys to ensuring radiation measurements are accurate and provide meaningful results is to ensure equipment is properly calibrated and operated. Proper operation begins with the formal and in-service training and is reinforced by reading the manufacturer's operating manual and through follow-up in-service training sessions. As for calibration, within the radiation detection industry, calibrations are normally performed at a frequency recommended by the manufacturer. Some equipment can be calibrated by BE personnel, whereas other equipment must be calibrated by a calibration facility. The date of the last calibration is usually identified on the survey instrument. It is important not to confuse "calibration" with "performance checks." Equipment performance should be checked before and after each use, IAW manufacturer's recommendations.

Another important aspect of operating radiation detection equipment, especially when approaching an unknown radiation field/source is to approach such a field/source from a safe distance. Place the instrument on its range setting that enables the detection of the lowest reading and advance slowly while carefully observing the meter. Then switch to a higher range setting as the maximum of the lower setting is reached. This is especially true with disaster or emergency responses. Equipment should be operating when leaving the BE office to monitor any increases over background during transit. Unloading and turning on radiation detection equipment after arriving at the entry control point is already too late!

The following paragraphs discuss primary radiation detection instruments used when conducting occupational and environmental health site assessments (OEHSA) and health risk assessments (HRA) and when responding to emergencies involving ionizing radiation.

ADM–300

The ADM–300 (fig. 2–8) is one of the many tools used to detect ionizing radiation. It is a key element in daily radiation surveys and radiological response capabilities. The basic parts are the main survey meter, three probes, and a cord to connect them. The ADM–300 is a portable multifunction survey meter kit. It can be used as a stand-alone unit or with one of the probes. The ADM–300 can detect and measure alpha, beta, gamma, and X-ray radiation. The cord pins should always be treated with care and never forced into probe or meter plugs or aggressively removed. The ADM–300 is a sensitive piece of electronic equipment and easily damaged, possibly resulting in mission failure and great health risks if mishandled!

Figure 2–8. ADM–300.

Capabilities

The ADM–300 can be used in the workplace for routine surveys or for response to radiological incidents/accidents. The various probes (alpha, beta, and X-ray) are lightweight, fairly easy to use, and give the user results in a matter of minutes.

Alpha detection uses scintillation (measuring in counts per minute [cpm]). Detecting alpha radiation requires the attachment of the AP–100 to the ADM–300 survey meter. The AP–100 should be held parallel to the surface, using a slow and steady sweeping motion less than 1/8 inch from the suspected contamination. This is due to alpha radiation traveling approximately 1 to 2 inches in air. Meter response time is slow; consequently, sweeping too quickly will either miss contamination or the location will be difficult to identify.

Beta radiation can be detected two different ways with the ADM–300: by attaching the Beta Probe (BP)–100 to the ADM–300 or by opening the shutter on the back of the meter. Beta is detected using a GM tube (measuring in cpm for the probe or mR/hr for the survey meter). Beta can only be detected and not accurately measured using the shutter. When the shutter is open, the ADM–300 is measuring *both* beta and gamma radiation; with the shutter closed, *only* gamma can penetrate. The difference in reading with the shutter closed and the shutter open are not an accurate measurement of beta radiation; the internal electronics do not distinguish energies that way. To get a good beta cpm reading, use the BP–100 probe. The probe should be held parallel to the surface, using a slow and steady sweeping motion, a few cms from the suspected contamination. This is because beta radiation can travel up to about 10 yards in air.

Gamma radiation is detected (measuring in mR/hr) using a GM tube located in the main body of the ADM–300. The ADM–300 detects gamma radiation when it is not connected to any of the probes and the shutter is closed. This type of detection may be used for the screening of gross contamination. The ADM–300, with the shutter closed, should be held parallel to the surface, using a slow and steady sweeping motion. It will detect gamma radiation from several meters away from a source because gamma radiation travels hundreds of yards in air.

X-ray radiation can be detected by attaching the XP–100 to the ADM–300. The detection principle used for this probe is scintillation (cpm). The XP–100 probe specifically detects low level “soft” X-rays in the form of energy levels (up to 60 keV) and should ONLY be used for nuclear weapons or lost source incidents; it should never be used for industrial surveys. The XP–100 probe should be held vertically to the surface, using a slow and steady sweeping motion, 18 inches above the surface of suspected contamination. There is a rod in the case that can be used to extend the probe closer to the ground. This is because X-ray radiation travels hundreds of yards in air.

The ADM–300 can be used to monitor/determine if radiation is present and how much exists; to monitor an area to provide early warning and radiological data; to monitor personnel, equipment, and resources for contamination; for aerial or ground surveys to determine the amount and the extent of radiation present in a given area (aerial surveys require additional equipment not available at the typical BE shop); and to conduct ground radiological reconnaissance.

Calibration

The ADM–300 should be calibrated by the manufacturer on an annual basis, and field checked by the user before each use and every 180 days. Faulty equipment should NEVER be used. The ADM–300 kit E, *Test/Verification Kit* is needed to field check the ADM–300. This kit contains radioactive check sources, Thorium–232 (Th–232) and Cs–137, and a test source container.

Operation

To prepare the ADM–300 for use, place two 9-volt (V) batteries into the back of the main unit. Visually check all probes for tears, holes, cracks, and missing or broken pins. If any are present, do not use the unit/probe(s).

Press and hold the POWER ON/OFF switch for two seconds to turn the unit on. The display should read “PLEASE WAIT.” The unit will conduct an automatic self-test. When it is finished, the “RATE” display and gamma dose rates will appear. The ADM–300 updates the display every two seconds. Turn the meter OFF each time a probe is changed or attached, and prior to field-checking each probe and obtaining a background reading. All background checks should be taken in an area free of contamination. Background readings are subtracted from all survey readings to obtain the true radiation reading.

Using the ADM–300 meter for gamma readings

After powering on the unit, the ADM–300 will display mR/hr readings. Ensure the beta window is closed. Hold the meter at a consistent angle and stand as close to the source of contamination as possible, without being overexposed, to ensure accurate and uniform readings are obtained.

Using the ADM–300 meter for beta and gamma readings

When the beta window is open, the ADM–300 meter is measuring beta and gamma radiation; however, the meter cannot distinguish between the two. Beta can only be detected, not accurately measured, using the meter without the BP. The beta window can be damaged by sharp objects, so extreme care should be taken to protect it.

Using the ADM–300 alpha probe for alpha readings

After powering on the unit with the AP–100 probe attached, the ADM–300 will display readings in cpm. Ensure the cover is removed from the face of the probe and hold the probe at a consistent angle. Always make a light check first by holding the probe up to the sun or other light source and ensure the meter reading does not spike.

Stand as close to the source of contamination as possible, taking care not to be overexposed. This will ensure accurate and uniform readings. Remember that the Mylar paper, located inside the probe window, can be easily damaged, so take extreme care to protect it. Slowly and steadily move the probe horizontally across the surface being monitored.

Using the ADM–300 beta probe for beta readings

After powering the unit on with the BP–100 attached, the ADM–300 will display readings in cpm. Hold the probe at a consistent angle and stand as close to the source of contamination as possible, without being overexposed, to ensure accurate and uniform readings.

Using the ADM–300 X-ray probe for X-ray readings

After powering on the unit with the XP–100 probe attached, the ADM–300 will display readings in cpm. Hold the probe at a consistent angle and stand as close to the source of contamination as possible, without being overexposed, to ensure accurate and uniform readings.

Victoreen

The Victoreen 451P (fig. 2–9) is another key component in the radiation instrumentation toolbox. It enables quick area surveys for radiation hazards and, in turn, keeps personnel safe. The Victoreen 451B and 451P are small, lightweight, hand-held, digital survey meters used to survey areas for radiation.

Figure 2–9. Victoreen 451P.

Capabilities

The Victoreen 451B and 451P are pressurized ionization chamber survey meters which can be used for a variety of surveys. Some examples include performing dental clinic X-ray surveys, NDI X- ray surveys of aircraft, and initial monitoring of potential hazard areas. They are also useful in measuring relatively high exposure rates. For example, the Victoreen 451B detects gamma and X-ray radiation above 25 keV and beta radiation above 1 MeV. Beta radiation readings are detected by opening the beta window. Due to its size and weight, the Victoreen can easily be carried to detect dose rate (microrem per hour [μR/hr], mR/hr, or R/hr) in seconds. The digital display makes readings and units of measurement easy to read, and it will automatically blink if 5 R/hr is reached. A backlight automatically comes on in environments with poor lighting. Two 9-V batteries enable the meter to operate continuously for over 200 hours.

Calibration

The Victoreen 451B and 451P should be calibrated by the manufacturer on an annual basis and self-checked by the user before each use. A Cs–137 test source should be used to calibrate the Victoreen 451B and 451P.

Operation

The Victoreen 451B or 451P can be used in three different modes. Depending on the type of survey being performed, the Rate, Freeze, and Integrate modes can be very helpful.

Rate mode

The Victoreen 451B and 451P are automatically in Rate mode when they are turned on. Hold the instrument in front of body, with arm extended (as close to the suspected contamination as possible) and use a slow and steady sweeping motion to obtain readings. Background should be subtracted from all readings obtained.

Freeze mode

Freeze mode shows the highest exposure rate on the screen from the time it is selected. The highest reading is shown as a single bar on the bar graph. The current reading will continue to be shown on the display. This is particularly helpful in obtaining dose rate information for X-ray machines. To activate freeze mode, press and hold the on/off button and MODE button at the same time until FREEZE shows on the display. To return to Rate mode, press the MODE button again.

Integrate mode

Exposures are accumulated using this mode. To activate the integrate mode, turn on the meter and press the MODE button. The mode can be zeroed out by holding the MODE button. To return to Rate mode, press the MODE button again. This feature is operational 30 seconds after the meter is turned on and any time after that.

SAM 940

The SAM 940 (fig. 2–10) is a *gamma-spectrometer* designed to be a lightweight, completely portable isotope identification system for radiological hazards. It is designed to be easily used by field responders for locating and identifying RAM. The SAM 940 offers rapid, on-site detection with ease of operation requiring minimal training. It can identify multiple radionuclides concurrently, thereby making it potentially useful in identifying unknowns. The detector can identify radioisotope ranges from 15 keV to 3 MeV and does not require annual calibration; however, repairs require units to be returned to the manufacturer.

Figure 2–10. SAM 940.

Capabilities

The SAM 940 can be used for a multitude of applications. Some of these include determining possible cleanup, personal protection, and treatment actions during and after a radiological contamination incident; the ability to identify health threats/hazards associated with radiological contamination during an initial OEHSA; and locating lost radioactive sources. The SAM 940 can also be used for the detection and identification of SNM. However, the system is not safe for use in flammable or explosive atmospheres.

Calibration

The SAM 940 auto power up sequence has a 30-second warm up and then is followed by data base set and auto calibration, which typically takes 1–1.5 minutes. Auto stabilization runs continuously in background.

Operation

There are three “soft keys” at the bottom of the screen (Identify, Background, and Finder), which are accessed by the “left” and “right” arrow keys. Press enter once the desired function is selected. The “Dial” and “Finder” screens can be used to locate RAM. Readings in the green region indicate proper source intensity for identification (gray indicates material is too far away, and red indicates material is too close).

Identification may be performed in any one of the four modes. Using the “Identify” function, a report is shown giving isotopes identified and the statistical confidence, based on source strength, length of acquisition, number of energy lines, and statistical factors.

Radiation Detection Company high volume air sampling kit

Radiation Detection Company (RADeCO) air samplers are portable, dependable, lightweight, variable flow “grab” type air samplers designed specifically for high-volume collection of airborne particulates or combination particulates. While there are different models in use throughout the BE community, we simply call the sampler a “RADeCO” regardless of the model. The BE community uses the RADeCO primarily for the collection of airborne radioactive particles.

Capabilities

The RADeCO is used to collect airborne particles following an incident suspected of releasing radioactive particles. The measurements obtained from the sample filter can aid in ensuring response personnel and the public are safe. It can also be helpful in recommending PPE, adequate shelter operations, and other hazard controls. The RADeCO is mostly used for sampling during nuclear weapons accidents, radiological dispersion device responses, or any other situations where there is a suspected release of radioactive particles.

Calibration

The RADeCO is initially calibrated at the factory using a 0750–09P (4” diameter HD–2061) filter. Annual calibration is required using either the D–8528 digital or C–8528 magnehelic air flow calibrators by a certified laboratory. A re-calibration, which can be accomplished in the BE laboratory, is necessary if the RADeCO is found to be operating outside of the calibration range (+/- 5% of the rotameter’s full-scale range).

Operation

Operation of the RADeCO is fairly simple; attach the filter holder with the desired filter media (with an “x” marked in pencil to show the collection side) to the sample inlet and connect the unit to a compatible power source.

NOTE: Some small generators will not produce sufficient current to run the RADeCO at calibration range; therefore, always test during training and do not wait until an actual incident to find out!

A fan on the RADeCO creates negative pressure and pulls air through filter paper. Particulates in the air are trapped on the filter paper and can be read with an ADM–300 or specialized laboratory equipment. The RADeCO should be placed on a tripod in a typical worker’s breathing zone (5–6 ft from the ground) facing into the wind. Place a RADeCO in the following locations: downwind and adjacent to release site; several hundred feet downwind; upwind of the release site (to obtain background readings); and at the contamination control station (if set up). Recording the initial and final rotameter readings and the time the sampler is allowed to run and then analyzing the filter with an ADM–300 provides the data necessary to calculate the concentration.

634. Performing swipe tests of radiological sources

RAM can be used for a variety of purposes. It is extremely likely that base organizations use and store RAM, to include radioactive *sources.* Sources are generally small metal containers in which a specific amount of a RAM is sealed.

Sources are typically enclosed in a housing to shield radiation. As long as they remain sealed, the housing remains intact, and the containers are handled and used properly, they present little health risk from the radioactive source inside. Radioactive sources come in a variety of shapes and sizes from button sources used for calibrating instruments to huge sources used in research.

Within the AF, any facility that uses and/or stores radioactive sources is required to have the source periodically assessed (swiped and/or wipe tested) to ensure they are not releasing and exposing personnel to high radiation levels. Sealed sources are commonly found in AF industrial, medical and research environments. The two types of radiological sources include *sealed* and *unsealed*.

A sealed source is one in which the RAM is bonded/fixed permanently in a container to prevent the release and dispersal of the material under the most severe conditions that are likely to be encountered during normal use and handling. Some sealed sources are subject to breakage and spillage; therefore, great care should be taken when handling sealed sources. Sealed sources must be tested for surface contamination (swipe sampled) and leakage every six months, or as specified by the label. This is referred to as *leak testing*.

NOTE: Leak testing methods can be specified by the manufacturer, by technical order (TO), or by a locally generated procedure. They typically involve wipe sampling specific areas of the device to determine if the material has leaked. In some cases, a swab may be used instead of a wipe for small enclosures. BE work centers should have written procedures for leak testing. In the case of RAM permit, if the procedure was submitted as part of the permit application, then the procedure is part of the permit and is mandated. Additional sampling requirements may be specified in the permit as well.

Unlike sealed sources, which are fixed permanently in a container, unsealed sources are not fixed or encapsulated and therefore present a greater risk. Proper control of unsealed sources is critical to prevent contamination or loss of source material. In locations where unsealed sources are used, swipe testing is performed to monitor any contamination.

There are multiple reasons why a radiological sample may be collected for laboratory analysis. It is critical that BE has a clear understanding of the purpose of a sample. This information must be effectively communicated to the lab so they can ensure proper analysis is performed and the results meet the needs of the customer. Once customers receive the results, they must be able to effectively interpret them. If any part of this process is not carried out effectively, then both time and resources are wasted.

Incomplete or incorrect information will delay sample results and can result in useless information. If there are any questions about how to sample and what to sample for, contact the lab's customer service. The lab will make every attempt to contact the base for missing information or to correct errors. If the lab does not receive a timely reply, a memo will be sent through the MAJCOM BE for investigation.

Wipe samples

Analytical results will be inaccurate unless careful attention has been given to sampling procedures. Wipe samples, also known as smears or swipes, provide a semi-quantitative measure of removable activity. They are collected by wiping an area using a filter paper while applying moderate pressure. The area of concern for wipe samples will usually be 100 square centimeters (cm^2). Current surface contamination guidelines are specified in terms of this area size. If a different area is wiped, as for objects with a smaller area, the area should be noted on AF Form 2753, Radiological Sampling Form. If the surface is thickly coated with particulate material, such as rust or dirt, a sample of the particulate material should be collected as a separate sample instead of attempting to use a wipe.

IMPORTANT NOTE: It is now recommended that swipe samples should be taken wet by adding a few drops of deionized (DI) water to dampen the swipe/swab. Previously, guidance was given that swipe samples should be taken using a dry swipe. Recent studies have demonstrated that this results in a very low collection efficiency of removable activity, as low as 10 %. It has been shown that wet swipes have a much higher efficiency of up to 90%. Thus, to obtain more representative samples, wet swipes are now recommended.

Not all surfaces are good for wipe samples. It is unlikely that outside surfaces, exposed to wind and rain, will have significant levels of removable surface activity. Further, wipe samples for removable surface activity are not appropriate for use on soil.

Materials

- Filter paper discs (Whatman® No. 41 or equivalent), 4.25 cm or less in diameter. Cotton tip applicator sticks may be used for wipe samples taken IAW TO 11H4–8–5–1, *Utilization and Maintenance of Cs-137*. The filter papers are standard non-medical items and may be obtained from Whatman Catalog (catalog no. 1001–042). ***Do not use wipe papers with "sticky" backs***.
- DI water.
- AF Form 2753 (1 per sample), pencil and pen.
- Small plastic sealable bag (1 per sample).
- Gloves.
- Tape measure or 100-cm^2 template.

Swipe test procedures

Protective Equipment: Always wear protective gloves when sampling to avoid contamination. If it is suspected that samples may be grossly contaminated, change gloves between each wipe to prevent cross contamination. When sampling, avoid touching the sample surface as much as possible.

Field blanks: A field blank is now required to be submitted for each batch of samples. For each batch of samples submitted (a batch is typically 1–20 samples), collect a field blank. A field blank is collected exactly like other samples but at a location nearby that is known to be free of radioactive contamination. For example, a field blank for a wipe can be accomplished by swiping a clean surface and submitting it with any group of swipes. If a field blank is not possible, then note this on AF Form 2753. Field blanks allow the lab to give more accurate results.

Place a small "X" IN PENCIL ONLY on the outer edge of the filter paper on the side that is to touch the radioactive source or area being tested for contamination. (Ink from a pen can interfere with laboratory analysis.)

Apply a few drops of DI water so the wipe is damp but not soaked. For surveys of small penetrations such as cracks or anchor-bolt holes, moistened cotton swabs may be used to wipe the area of concern. If a cotton tip applicator is used, apply a drop of DI water to the top of the applicator. All wipes, except for tritium swipes, are placed in an individual plastic sealable bag to prevent cross-contamination while awaiting analysis. Tritium swipes are immersed in liquid scintillation counting vials, provided by the laboratory, immediately after wipe collection.

Before swiping, check the filter paper with an ADM 300 with probe or an instrument capable of measuring beta/gamma to establish background reading.

In a slow back and forth "S" motion applying moderate pressure, swipe a 100 cm^2 area. Repeat the process at a 90-degree angle direction, using the same wipe (fig. 2–11). If a cotton tip is used, wipe as much of the area that may be contaminated as possible using moderate pressure up to 100 cm^2. Use caution not to bore a hole through the paper.

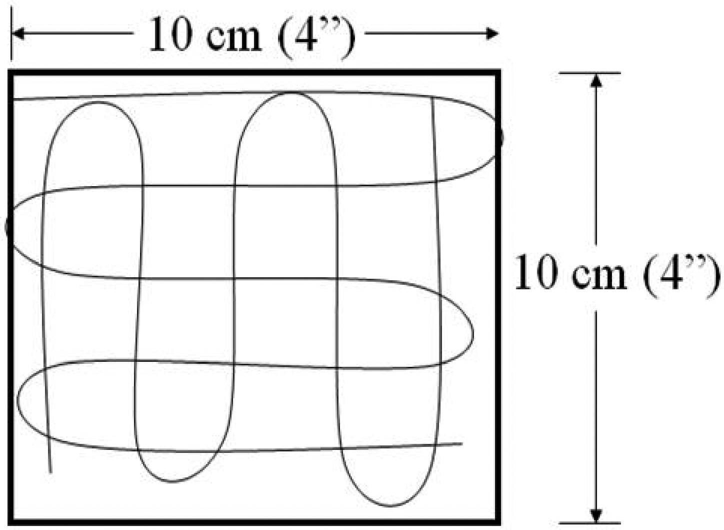

Figure 2–11. Swipe sample.

After completing the swipe, allow the sample to dry, then measure the "X" side of the filter paper to determine the gross count rate. If the activity is below the original background reading, the source is in good condition and is not leaking. If the activity is above the acceptable limits, it is considered leaking.

Post-swipe procedures

Place the unfolded disc (or cotton tip stick) in the plastic bag (if necessary, applicator sticks may be broken to fit the bag). Remove the gloves and place them in a plastic bag to be surveyed for potential radioactive waste.

Complete AF Form 2753 and record the sample information as appropriate. Write the sample number on the plastic bag and attach the form (by stapling) to the bag. Make sure to document the area sampled in the comments section of AF Form 2753. The following are a few tips on how to complete AF Form 2753.

- Be specific with analysis and nuclide, if known.
- Include complete sender information including base code, base sample number, DSN, etc. Additionally, include an alternate contact who can answer questions about the sample if the primary is not available.

Monitor the outside of the envelope, the surveyor's hands, and the gloves worn. Do not send the envelope if the exterior surface exceeds 0.5 mR/hr. The envelope is sent to the radioanalytical laboratory at USAFSAM.

When the results are received from the laboratory, compare them to the acceptable removable activity standard. Swipe results should be documented and maintained in a log for minimum of three years.

Procedures for other types of sample collection, such as wipe collection for tritium and biological samples, can be found in the U.S. Air Force School of Aerospace Medicine Laboratory Sampling and Analysis Guide, November 2016 (AFRL-SA-WP-SR-2016-0023), available on the Environmental, Safety, and Occupational Health (ESOH) Service Center Analytical Services web page and https://apps.dtic.mil/dtic/tr/fulltext/u2/1021554.pdf.
USAFSAM *Laboratory Sampling Guide*, 11 May 2012 (AFRL-SA-WP-SR–2012–0008) available at the ESOH Service Center Analytical Services web page (https://hpws.afrl.af.mil/dhp/OE/ESOHSC/pages/index.cfm?id=742).

635. Surveying radioactive materials for shipment

The basis behind the regulations governing the packaging and shipping of RAM is to keep radiation and RAM from affecting the environment during transportation and to keep the environment from affecting the integrity of the RAM.

The transportation of RAMs is regulated jointly by the NRC and the DOT. The NRC requires RAMs to be shipped IAW the hazardous materials transportation safety regulations prescribed by the DOT. An estimated four million packages containing RAM are shipped every year. Therefore, the DOT prescribes limits on the maximum amount of radioactivity that can be transported in these packages to ensure personnel are protected from unnecessary exposures.

When a package containing RAM is received or is ready for shipment, the transportation flight will contact BE to monitor the package. Packages are monitored for the following:

- External radiation levels – electromagnetic radiation.
- Contamination – particulate radiation.

Always wear the proper protective clothing during the monitoring process to prevent contamination and unnecessary exposures.

Monitoring external levels – gamma and X-ray radiation

External radiation levels are monitored with portable ion chamber instruments, such as the Victoreen 450, Victoreen 451, or Victoreen 451P. Readings are taken at approximately 10 cm (4 inches) from the source and also from the surface of the package. Radiation levels must not exceed 10 mrem/hr from any point on the external surface of the *unpackaged* material or 0.5 mrem/hr at any point around the *external surface* of the package.

Monitoring contamination – particulate radiation

RAM shipments are swipe tested for external particulate contamination on the package surface using a 4.25 cm Whatman 41 round filter. Swipe an area of 300 cm^2 on the surface of the package, then monitor the swipe paper with an ADM–300 and applicable probe (depending on item being checked). Send the swipe paper IAW the wipe sampling procedures listed in the previous section. Note the difference between the area wiped for leak testing (100 cm^2) and the area wiped for shipping (300 cm^2).

The amount of radioactivity measured on any single wiping material, when averaged over the surface wiped, cannot exceed the limits set by the DOT (outlined in the following table) at any time during the transport process.

Transportation Process			
Contaminant	**Maximum Permissible Limits**		
Beta and gamma emitters and low toxicity alpha emitters	0.4 Bq/cm^2	10^{-5} $\mu Ci/cm^2$	22 dpm/cm^2
All other alpha emitting radionuclides	.04 Bq/cm^2	10^{-6} $\mu Ci/cm^2$	2.2 dpm/cm^2

Where: Becquerels per centimeters squared is represented as Bq/cm^2; microcuries per centimeter squared are represented as $\mu Ci/cm^2$; and disintegrations per minute per centimeters squared are represented as dpm/cm^2.

636. Performing ionizing radiation surveys

Despite the benefits that radiation provides to healthcare and industrial applications, these operations can pose some health risk. Exposure to radiation, even at very low dose rates, is permissible only when the benefit derived from such exposure exceeds the risk incurred. This lesson serves as an introduction to the type of surveys performed on ionizing radiation, primarily X-ray machines in medical/dental areas and NDI shops (shielded and unshielded surveys). Many of the radiation safety concepts and principles apply to both medical/dental and industrial applications. However, there are some differences in procedures to perform these assessments.

Ionizing radiation survey program

The objective of an effective ionizing radiation survey program is to provide safe diagnostic tools while at the same time protecting workers, patients (medical applications), and the general public from hazardous radiation exposures. To this end, medical and industrial X-ray generators must be surveyed for leakage, scatter radiation, hazard distances, and inspected periodically for proper operation and changes to equipment or operations.

There are various types of surveys performed on ionizing radiation/x-ray generators; some are performed by the BE flight and some by other agencies. The X-ray surveys performed by the BE flight focus on the following four general areas:

1. Source inventory.
2. Radiation safety review.
3. Quality assurance.
4. Radiation measurements.

Source inventory

Recall from a previous lesson that an inventory of all emitters or "sources" is an integral part of an ionizing radiation safety program. It lists specific information about the emitter such as type, model and serial numbers, location, and maximum rated mA and kVp. Information on all X-ray producing sources is verified annually and updated as sources change.

With regard to X-ray generating machines, the term "source" refers to the tube head, not one entire X-ray setup. For example, figure 2–12 displays a medical diagnostic unit in which the radiographic tube is one source and the fluoroscopic tube is another. Industrial X-ray units are designed differently.

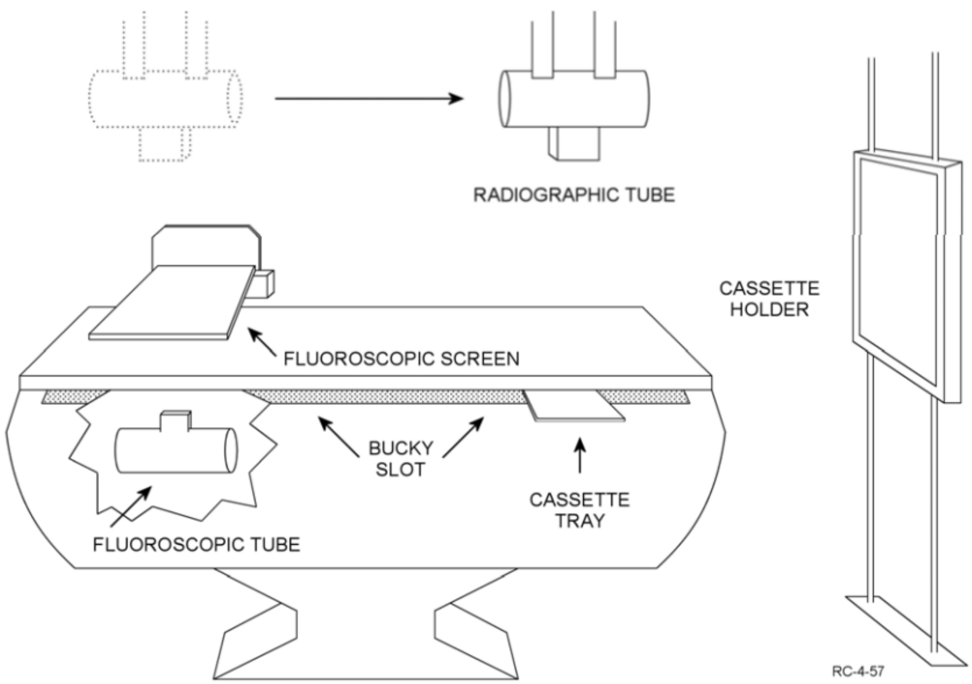

Figure 2–12. Medical X-ray room set up.

Radiation safety review

A review of radiation safety information/data, such as safety practices and facility/equipment design, will constitute a major portion of a radiation scatter survey.

Safety practices

As mentioned earlier, medical/dental and industrial X-ray operations share many safety concepts; however, industrial operations can have a greater degree of control. This is because industrial operations do not have the added complexities associated with patients and are easier to control from a technical standpoint. The proximity of patients and visitors in the medical environment brings a greater level of concern for public exposure as well. Industrial X-ray operations, due to the locations where they are performed, are not typically accessible to the general public. However, precautions need to be taken to ensure that workers not involved in the X-ray operation are kept at a safe distance.

The individual conducting the radiation safety program inspection investigates the adequacy of safety practices designed to avoid unnecessary exposures (e.g., medical radiology technicians should not hold patients being X-rayed); presence and proper use of radiation warning signs and signals; and proper use (wear) and storage of personal radiation exposure measuring devices (such as TLD) and PPE. It also includes a review of written safety procedures to follow when an unexpected exposure occurs.

Facility/equipment design

Facilities and equipment are designed with safety features to prevent unnecessary exposure. For example, industrial X-ray units may have long cords for the control unit to allow workers to operate the X-ray unit from outside a hazard area. However, medical technicians must be in the room with a patient; therefore, the technicians are afforded a shielded booth to stand behind. Inspectors investigate and verify the adequacy and condition of safety features.

With regard to facility design, there is an important distinction that has an impact on safety procedures. For example, there may be a facility that provides a shielded operation, where exposures are enclosed in a controlled area. Conversely, there may be an unshielded operation, where exposures may be conducted in open bay hangars. Further, there may be flight lines in deployed locations, or in other locations for EOD and OSI operations.

Medical diagnostic X-ray suites should be designed with ALARA practices in mind. Typically, these facilities have lead shielding in the walls, operator booth, and in and around doors and film pass-through boxes. Keep in mind, however, that portable X-ray units are used in other areas of the medical facility such as surgical suites, emergency rooms, or surgical wards. Typically, these areas are not shielded.

Only a few of the NDI facilities in the AF are completely enclosed with shielding; these facilities are expensive to build and often unnecessary due to the limited workloads of many NDI sections.

In general, shielded operations will have fewer administrative requirements than unshielded ones because unshielded operations inherently have more safety concerns. Also, engineering controls in shielded facilities make them inherently safer.

Quality assurance

Quality assurance focuses on ensuring the X-ray machines operate properly to consistently produce high quality images with minimal radiation exposure to workers and patients. One of the benefits of quality assurance is reducing the number of retakes thus reducing unnecessary exposure. BE does not evaluate the direct output of X-ray machines but can verify these tests have been performed.

All medical/dental X-ray equipment manufactured or sold in the US must meet technical performance requirements of Title 21 CFR 1020, *Performance Standards for Ionizing Radiation Emitting Products*. It is AF policy that all new procurements are certified to meet these requirements. Technical performance testing, which involves measuring the direct beam output of the unit, is performed by a medical equipment repair center (MERC) technician with specialized equipment. Technical performance testing of diagnostic radiological systems should be performed prior to first clinical use (called acceptance testing) and periodically thereafter. Direct beam output of all medical X-ray equipment must be measured annually, and every four years for dental equipment. The BE flight performs scatter surveys (not acceptance testing) on medical X-ray units to ensure workers, patients, and members of the public are not exposed to unnecessary radiation.

Radiation measurements

Scatter radiation surveys are required before initial use of the X-ray machine and then only when there are changes in the operation, such as modifications to the X-ray machine, changes in the building structure that affect shielding, or significant changes in the workload.

Measurements of radiation fields are made to provide a basis for estimating the dose equivalents that personnel may receive and/or establishing hazard areas. Operating conditions (beam orientation, source outputs, locations of operations and the surrounding environment, etc.) will influence measurement locations and the number of measurements required. Identify nearby workstations and determine the present and expected occupancy of the workstations and adjacent areas, then measure and record radiation exposure rates in these areas.

Medical diagnostic X-ray surveys

These types of measurements can be conducted with portable survey instruments or with passive TLDs. The TLD method is discussed briefly here; however, the remainder of this lesson focuses on the portable instrument method.

TLDs

The advantage of using TLDs is that calculations are virtually eliminated and it is the easiest and most accurate method of measuring radiation. The integrated exposure result only needs to be converted to an annual exposure. The disadvantages of TLDs are that there are practical limits to the number of measurement locations and the time involved.

TLDs are placed in areas of suspected radiation exposure such as the exposure room, operator's booth, and adjacent offices and hallways. They are taped to a wall at chest height next to a sign warning people not to touch the device. The TLDs are left in place for a predetermined amount of time, such as three months, to obtain reliable data. While in-place, the TLDs register X-rays that pass through them. At the end of the sampling time, the TLDs are collected and sent to the USAFSAM RDL for analysis.

Portable instruments

Portable instruments (such as an ion chamber) can be used to evaluate scatter radiation leakage through voids in shielding (i.e., utility conduits and vents) and the junction of different shielding types (i.e., wall/glass interfaces and door/wall interfaces).

Compared to TLDs, this method requires more effort and cooperative participation between the BE flight and radiology technicians. Radiology technicians operate the X-ray unit while BE personnel collect measurements in and around various areas. After measurements are collected, the radiation exposure from one procedure can be used to calculate an annual exposure based on the estimated number of the same type of procedures performed annually.

X-ray room layout and measurements

Medical diagnostic X-ray surveys are concerned with scattered radiation inside the examination room, stray radiation outside the examination room, and leakage radiation from the X-ray tube housing. Figure 2–13 shows the layout of a typical medical X-ray room. Pay particular attention to the protective enclosure where the radiology technician stands while taking X-rays and the adjacent hallway and occupied areas; these are areas of concern for radiation exposures to both technicians and the general public.

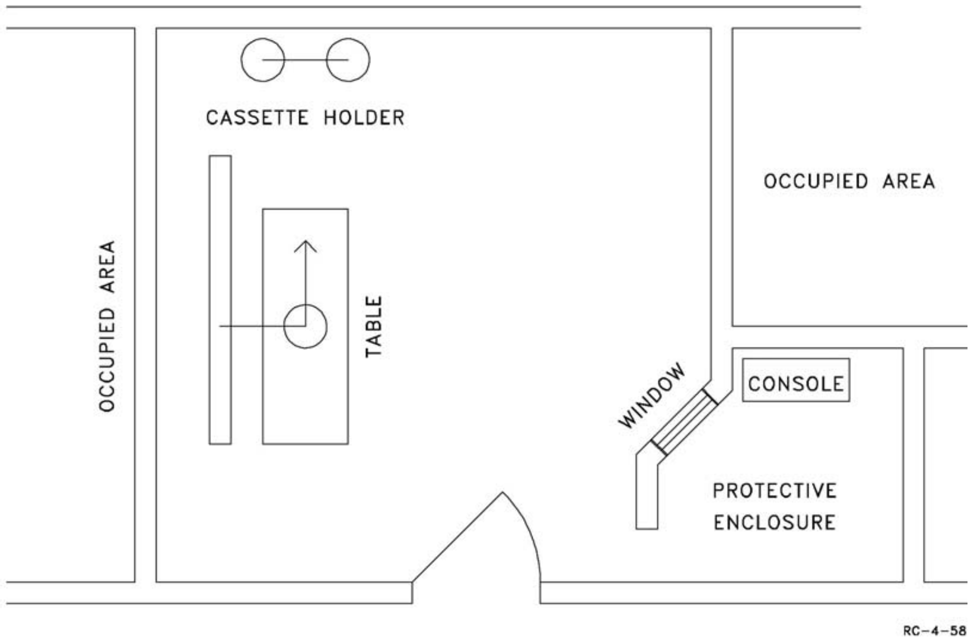

Figure 2–13. Typical X-ray room.

X-ray machines can be oriented in different positions to perform the particular exposure needed. For example, a unit may be pointed down towards the table or horizontally; towards a chest cassette holder that is typically mounted on a wall. Dental X-ray units are also pointed horizontally at both sides of a patient's mouth. X-rays are usually taken with the X-ray tube head arranged to simulate practical conditions of operation that will result in the greatest exposure at the point of interest. Typical measurement points of interest include the operator's position (typically behind the shielded protective enclosure), film pass through opening, and exterior walls focusing on the door area, behind the chest X-ray cassette holder, and above and below the X- ray suite if occupied by individuals.

Usually, measurements are collected about 3 ft above the floor levels, since this level is mid-torso for most individuals, and measurements collected for radiation fields penetrating surfaces like walls should be 30 cm (12 inches) from the surface. In general, except for some fluoroscopic exposures, most exposure times in diagnostic X-ray are a fraction of a second. This makes exposure rate measurements impractical, since the response time of many instruments is on the order of a few to over eight seconds. While some X-ray machines can be safely operated for several seconds, there is risk in damaging the tube. For short duration exposures, measurements should be taken with an ion chamber instrument capable of integrating (adding) exposures. If sufficient response with an ion chamber using integrate mode is not received during a single exposure, multiple shots should be accomplished and recorded.

Preparing X-ray unit

X-ray machines are susceptible to damage from over-heating. For this reason, an experienced radiology technician should be present for the measurements to aid in setting up the equipment in modes that are used for patient exposures and operating the equipment to ensure it is not damaged.

In regard to X-ray unit operating settings, the parameters of interest are kVp and mAs. In general, for most diagnostic equipment, 100 kVp and the maximum mAs setting of the X-ray unit are reasonable settings to accomplish the survey.

Seldom is it possible to conduct measurements during actual patient examinations. In order to properly recreate the scattering effect that normally takes place during radiographic exposures, a scattering medium, normally a one-gallon plastic container filled with H_2O, is placed in line with the beam.

Survey procedures

Recall the focus areas of an X-ray survey are source inventory, radiation safety review, quality assurance, and radiation measurements. As part of the survey, source inventory data is reviewed and updated to reflect any changes, and radiation safety features are inspected for condition and placement. Following are the general procedures for collecting measurements.

- Sketch the room including adjacent areas.
- Determine measurement points.
- Have radiology technician set unit operating parameters.
- Place scattering medium (gallon container).
- Select appropriate range on the survey meter.
- Position survey meter.
- Have the radiology technician activate the X-ray unit and simultaneously observe survey meter.
- Record readings.

Data collection and results interpretation

The annual exposure is the product of several factors, including exposure per integrated current, the annual integrated current, and occupancy factor (OF). In other words, how much radiation is being produced per exposure, how many exposures are shot per year, and how long an individual might be exposed to the scatter/stray radiation are areas of concern.

Once measurements have been taken, estimated annual exposures must be calculated for each area of concern. Annual exposure calculations begin with determining the exposure per shot and multiplying that by the estimated number of shots per year and the OF. An OF is the fraction of the duty day an area of concern is expected to be occupied. The following table lists the OFs suggested by the National Council of Radiation Protection and Measurements.

OF	Area
1	Administrative or clerical offices; laboratories, pharmacies, and other work areas fully occupied by an individual; receptionist areas, attended waiting rooms, children's indoor play areas, adjacent X-ray rooms, film reading areas, nurse's stations, and X-ray control rooms.
0.5	Rooms used for patient examinations and treatments.
0.2	Corridors, patient rooms, employee lounges, and staff rest rooms.
0.125	Corridor doors.
0.05	Public toilets, unattended vending areas, storage rooms, outdoor areas with seating, unattended waiting rooms, and patient holding areas.
0.025	Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop areas (unattended), attics, stairways, unattended elevators, and janitor's closets.

Remember, measurements were taken with the highest settings used. If calculated annual exposure is less than the appropriate limit, no more calculations are necessary. If calculated annual exposure is more than the appropriate limit, measurements must be taken for each setting used and multiplied by the number of exposures per year at each setting. Then, the annual exposures for each setting need to be added together before comparing to the appropriate limit. Fortunately, the worst-case calculations are almost always below limits with modern equipment, facility designs, and safety practices.

To determine the number of shots taken per year, information about the workload and X-ray unit, operating parameters must be collected. Figure 2–14 is an example of X-ray procedures and operating parameter information that is recorded annually. In this case, the number of shots per year used is 2,100 for the worst-case calculation.

Procedure	Integrated Currect (mA·s) per Procedure	Tube Potential	Number of Procedures Annually	Annual Integrated Current (mA·s) *
Chest	30	80	1,000	30,000
Full Spine	50	90	500	25,000
Abdomen	80	100	600	48,000
			Total	103,000

** (Annual Integrated Current = Integrated Current per Procedure X Number of Procedures Annually)*

Annual Integrated Current for Chest Procedure: 30 X 1,000 = 30,000

Figure 2–14. Radiographic procedures and parameters for example X-ray suite.

There are several agencies that use industrial X-ray units, but NDI is the most common application at AF installations. NDI radiography operations are conducted in both shielded and unshielded facilities. Shielded facilities have sufficient shielding/protection to limit exposures on the outside of the facility. Unshielded applies to X-ray operations where fixed shielding cannot be used (e.g., flight line, open hangars, etc.). Unshielded operations require additional safety features, compared to shielded, and the protection of personnel and public depends almost entirely on strict adherence to safe operating procedures.

The X-ray machines used by NDI are more powerful and are activated for longer periods than are those used for medical diagnostics; therefore, the danger is greater. However, many of the survey techniques are similar to those used to perform medical X-ray surveys.

The primary purpose of survey measurements is to delineate restricted areas and determine appropriate control measures to ensure ALARA and dose limits are adhered to. For shielded facilities, measurements are conducted primarily to verify the effectiveness of the shielding.

TO 33B–1–1, *Nondestructive Inspection Methods, Basic Theory*, has the most extensive safety specifications among AF radiation operations.

Measurement methods

Several radiation detection instruments are suitable for mR during NDI operations; however, IAW TO 33B–1–1, ion chambers will be used. Like medical X-ray surveys, the Victoreen 451P is normally used.

TLDs can be used as a supplement to portable survey instrument measurements in evaluating exposures. While they can be used for short-term measurements, they are most commonly used for evaluating long-term exposures (calendar quarter) where the results can be normalized to estimate adherence to annual general public exposure limits. High exposure rate environments should be measured remotely using integrate or “Freeze” modes. Using remote measurement methods like these are consistent with the ALARA principle. Before even beginning a measurement survey, ensure good radio communication with the operator and the area is roped off and clear of all personnel.

Room layout and measurement locations

When surveying shielded NDI facilities, measurements are collected in all adjacent areas accessible to personnel. The measurements are made with the equipment configured in such a way that is consistent within normal operation configurations that results in the greatest exposure risk at the point of interest. For example, if any of the normal configurations position the tube head pointed in the direction of the shop area, the unit would be configured as such when collecting measurements in the shop area.

Recall that few NDI facilities are shielded; most perform radiographic exposures in unshielded facilities such as hangars, especially when inspecting aircraft. In unshielded facilities, measurements should be collected at locations likely to be occupied by personnel during exposures, like the console, observer location, and offices. Further, take measurements at any access points to the facility. Additionally, while locations within the facility should not be occupied during exposures, it is a good practice to assess potential exposure rates in the unoccupied areas for the purpose of evaluating the maximum hazard potential of the environment.

For most NDI operations, multiple exposure configurations will be used. As such, delineation of restricted areas in and surrounding a hangar will require analysis of all scenarios to ensure adequate protection for non-radiation workers and members of the public. High exposure rate environments are to be expected in unshielded industrial X-ray operations. These should be measured remotely using integrate or “Freeze” modes.

Assessing a shielded facility usually involves locating a contour of the restricted area within which “2 mR in any one hour” would be exceeded. “Within one hour” allows the time of the survey to be factored into the compliance consideration. This is different than an exposure rate of 2 mR/hr, which specifically ties to the measurement (which assumes a continuous one-hour dose). The 2 mR/hr level is sometimes used as the default and is typically considered an acceptable exposure rate because radiation workers could be exposed at this level, 40 hours per week and 50 weeks per year, without exceeding the 5-rem annual dose limit. Most people do not even receive close to that dose, so this is a very conservative limit. But it is okay to be conservative to keep the exposures ALARA regardless of the limit. Although, radiation workers can occasionally be exposed to higher levels for short/limited periods of time, the contour of the 2mR/hr distance from the source or other structural shielding is mainly used to ensure control of the area is maintained.

To establish the 2 mR/hr line, the basic approach is to start where the NDI operator is located. Make sure the tube head is directed away from the operator. Then with the appropriate meter set to measure rate, begin the X-ray operation and watch the rate for a 2 mR/hr reading. Slowly back away or move closer until a reading of 2 mR/hr is achieved. Follow the 2 mR/hr level around the facility or area to determine the extent of the 2 mR/hr contour. If rates rise rapidly, or control of the area is lost, use the radio to have the unit shut off. Be aware that the contour may not be smooth. There can be some “hot” spots found during NDI operations.

Preparing the X-ray unit

The parameters of interest are kVp and mA as with medical diagnostic X-ray surveys. In general, measurements are made with the X-ray unit operated at the highest kVp and mA settings used for actual inspections.

Survey procedures

The following are the general procedures for collecting measurements:

- Sketch the room, including adjacent areas.
- Determine measurement points.
- Have the NDI technician set the unit operating parameters.
- Have the NDI technician position the X-ray unit.
- Select the appropriate range on the survey meter.
- Position the survey meter.
- Have the NDI technician activate the X-ray unit.
- Record the reading.

- If necessary, establish the 2 mR line.

Data collection and results interpretation

Hourly exposures for occupationally exposed workers, and annual exposures for general public and non-radiation workers, must be calculated for each area of concern. The way in which annual exposures are calculated differs slightly from medical X-ray surveys; however, the data needed is similar. The following formulas are used for calculating hourly and annual exposure.

$$Hourly\ Exposure\ Rate = IE \times T_{Beam} \frac{60\ min}{1\ hr}$$

IE = integrated exposure measurements.
T_{Beam} = length of exposure (minutes).

$$Annual\ Exposure = OF \times ME_{1hr} \times T$$

OF = Occupancy factor.
ME_{1hr} = Maximum exposure in one hour.
T = Hours of use per year.

To calculate hourly and annual exposures, the following data is needed:

- The annual NDI workload for the facility.
- Length of exposures.
- Radiation measurements.
- Occupancy factors.

Workload data can be estimated or based on actual NDI exposure log information. Occupancy factors differ from those applied to medical environments; however, the purpose is the same in that it's a way to estimate the fraction of time an area of concern is expected to be occupied during a duty day. See the following table for OFs for shielded NDI facilities.

OFs for Shielded NDI facilities	
Occupancy	**Area**
Full (100%)	X-ray control space and waiting space, darkrooms, film reading areas, workrooms, shops, offices, corridors large enough to hold desks, and occupied space in adjoining buildings.
Partial (25%)	Worker restrooms and occupational use corridors too narrow for desks.
Partial (12.5%)	Public corridors too narrow for desks, utility rooms, and employee lounges.
Occasionally (5%)	Restrooms or bathrooms, storage rooms, vending areas, and outdoor seating.
Rare (2.5%)	Outside areas used only for pedestrian/vehicular traffic, unattended parking lots, attic or crawl spaces, stairways, unattended elevators, and janitor closets.

Just as health risk and potential exposure to machine made radiation must be evaluated, RAM also presents ionizing radiation health risk that must be evaluated. There are specific requirements when dealing with RAM.

Radioactive material storage and use surveys

RAM is material that contains unstable (radioactive) atoms that give off radiation as they decay. The radiation emitted may be alpha or beta particles, gamma or X-rays, or neutrons. In any area in which RAM is stored or used, periodic assessments must be performed to determine the exposure risk to workers and the general public.

AF organizations possessing RAM are responsible for providing security for RAM. IAW AFMAN 40–201, BE flight must conduct annual surveys where RAM are received, used or stored. The following are the two purposes for surveying RAM storage and use areas:

1. Determine the classification of the area.
2. Analyze radiation exposures to workers and the general public.

Areas in proximity to radiation sources are classified based on radiation levels that are present in the same area. More specifically, it pertains to the effective dose of radiation that people in the area may receive over a time frame. The purpose of the classification is to ensure exposures are within applicable standards, to align with ALARA, and aid in determining necessary surveillance, postings, and other requirements. The dose in any unrestricted area resulting from USAF controlled radiation sources will not exceed 2 mrem in any one hour (at 30 cm from the source), or 100 mrem in a year, with occupancy and use factors taken into account.

While annual surveys must be accomplished in areas to verify adherence to annual radiation exposure limits, performing measurements each year may not be necessary. For some storage and use areas, verifying that current operating conditions are the same as those that existed during the initial survey is sufficient.

Instrumentation

Storage and use area measurements are conducted using portable radiation survey instruments. USAFSAM Radiation Surveillance guidance cites the Victoreen 451B, 450, and Eberline RO–20 as optimal instruments for these types of surveys. However, the Victoreen 451P, 450P, and ADM–300 will provide acceptable results. The instrument should be checked for proper operation and calibrated with a check source prior to collecting measurements. The annual calibration should also be verified as current. TLDs may be used to measure annual total equivalent dose estimates; however, they are not the method of choice. They cannot be used to measure hourly total equivalent dose estimates.

Room layout and measurements

As with X-ray surveys, room and building layout and activities conducted within the building play an important part in determining measurement locations. Keeping this in mind, take measurements near the storage container, at workstations in the vicinity of the container, and in work areas adjacent to the storage area, to assess the potential for radiation exposure in excess of standards.

Figure 2–15 illustrates an example of a RAM storage area and other areas in the vicinity of the storage cabinet. In this example, the cabinet is located on an exterior wall, with a technician’s desk positioned in the same room.

Location #1 is 30 cm (approximately 1 foot) from the exterior of the cabinet, and location #3 is 30 cm from the exterior wall directly adjacent to the cabinet, to determine effective dose levels close to the source(s) with respect to the 2 mrem in any one hour standard.

Measurements at workstations in the vicinity of the container and in adjacent rooms are collected to assess potential exposures to employees and members of the general public. Locations #2, #5, and #6 were selected to evaluate exposure to the technician that works and has a desk in the room. Location #7 in the corridor was selected to assess potential exposures to members of the general public or employees that do not work in the immediate area. Finally, location #4 is a workstation located in a room adjacent to the storage area selected to assess worker exposures in that area.

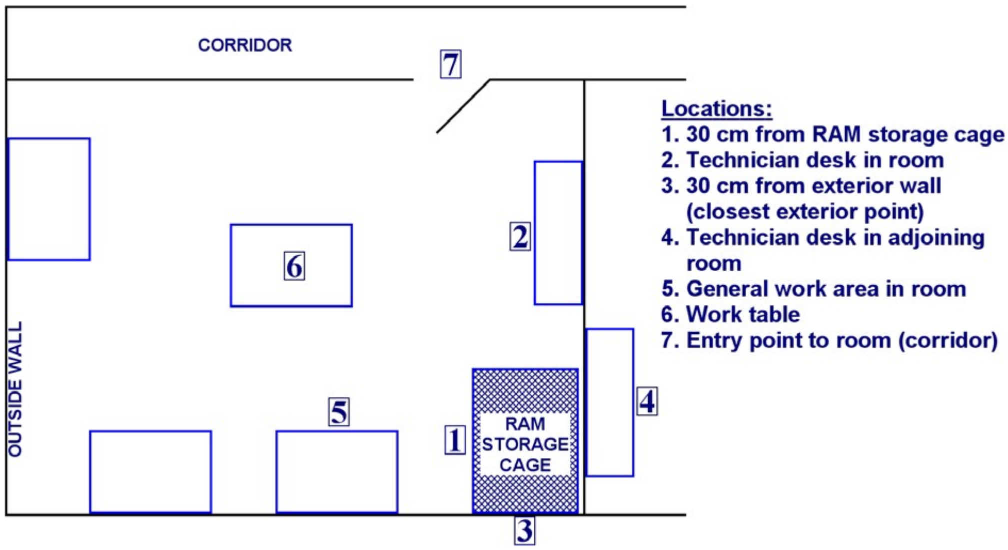

Figure 2–15. Example of RAM storage area.

Date collection and results interpretation

At a minimum, survey documents should diagram the RAM storage/use area (fig. 2–16) with details on the following:

- Adjacent areas.
- Information on the RAM or radiation producing devices being used/stored.
- Instruments used for the survey with serial number and calibration specifications.
- Individual(s) conducting the survey.
- AF permit number (if applicable).
- Measurements.
- Exposure evaluation conclusions (i.e., the area is unrestricted/restricted, meets or does not meet public exposure limits, etc.).

Once measurements have been collected, they are compared to the 2 mrem in any hour criterion; estimated annual exposures must be calculated and the values compared to the 100 mrem per year criterion. The 2 mrem/hr line may be more appropriate here than it was for X-ray machines, since RAM is not 'turned off' in between uses. However, RAM is typically stored in shielded containers; therefore, both shielded and un-shielded measurements may be necessary if RAM is stored and used in the same vicinity.

Radioactive Material Storage Area Survey for Materials under
USAF Permit Number NM-XXXXX-XX/XX

Survey Location: In and Vicinity of Room XYZ, Building ABC, Best AFB NM
Using Organization: XYZ AMDS/SGPB

Radioactive Material: Small Check Sources for ADM-300, NITON Gauge w/ Ni-62 & Am-241, M8A1/M43A1s w/ Am-241, ICAMS w/ Ni-63, and Compasses

Surveyed By: SrA Mike Johnson Date: 19 Apr 10

Survey Instrument: ADM-300 (internal G-M) Calibrated: 05 Jan 10 Due: 04 Jan 11
Serial Number: 00213 Background Exposure Rate: 15 µR/hr

Locations	Net Exposure Rate (µR/hr)
1. 30 cm from RAM storage cabinet	20
2. Technician desk in room	10
3. General work area in room	10
4. Closest point in corridor to cabinet	15
5. Entry point to room (corridor)	5
6. Technician desk in adjoining room	5
7. 30 cm from exterior wall (closest point on exterior)	5

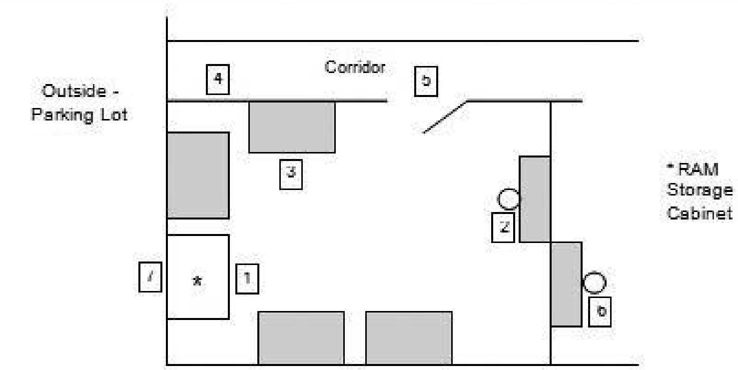

Figure 2–16. Example RAM storage area - survey measurement documentation.

637. Investigating suspected ionizing radiation overexposures/abnormal exposures

One of the responsibilities of the IRSO is to report and investigate *abnormal exposures* and *overexposures* to ionizing radiation. AFMAN 48–125 explains procedures for conducting investigations. An abnormal exposure is an exposure received in any monitoring period that is acceptable for that specific period but which would be an overexposure if continued at the same rate. Overexposure is exceeding a regulated exposure standard.

Abnormal exposure suspected by base

If a dosimeter is suspected to have received an abnormal exposure, forward the dosimeter to the radioanalytical laboratory together with the control dosimeter and a letter detailing the circumstances involved in the incident. Suspected abnormally exposed dosimeters will receive priority processing at the radioanalytical laboratory; the dose results will be reported back to the IRSO as soon as they are available.

Abnormal exposure observed by laboratory

If an abnormal exposure is observed by the radioanalytical laboratory, the laboratory will notify the IRSO by telephone (within 72 hours) and follows-up with a facsimile memorandum of apparent abnormal exposure. The memorandum accomplishes the following:

- Identifies the dosimeter and/or bioassay sample number.
- Includes the name, social security number, and occupational code of the individual involved.
- Gives dose equivalent estimate based on dosimeter results, bioassay concentrations, or both.
- Provides instructions to accomplish the required investigation.

The IRSO then initiates a formal investigation into the cause of the exposure.

Investigating abnormal exposures

The following steps are for investigating abnormal exposures:

1. Interview the worker.
2. Validate the exposure.
3. Identify corrective action.
4. Document the investigation.

Interviewing the worker

The IRSO conducts the investigation but may need assistance. The investigation begins by interviewing the exposed worker and area supervisor to determine the circumstances surrounding the abnormal exposure. If you work together, review such things as work load and practices, dosimeter storage practices, and any other factors that could have potentially contributed to the exposure to determine the cause. Potential root causes of abnormal exposure can include deliberate exposure of the dosimeters, dosimeter worn while the individual concerned received diagnostic or therapeutic radiation exposure as a patient, improper action on the part of the individual in question, inadequate protective measures, faulty operation of equipment, or use of the dosimeter for other than personnel monitoring, etc.

Validating the abnormal exposure

Once this information is collected, the IRSO can then validate the exposure. If it is determined that the individual's dosimeter reading is erroneous, for whatever reason, the IRSO can invalidate the exposure. If the abnormal exposure cannot be invalidated, then the investigation continues by determining the portion of the body exposed.

Identifying corrective actions

If it is determined that the exposure could have been prevented, corrective action should be taken to prevent reoccurrence. Depending upon the findings of the investigation and the root cause, appropriate corrective actions might include instruction on the proper wear and uses of the dosimeter, ensuring the adequacy of the radiation protection program, surveying and correcting faulty equipment, moving the dosimeter storage area to an area free of radiation sources, etc.

Documenting the abnormal exposure

After completing the investigation, the IRSO must submit a written report on the findings of the investigation. AFMAN 48-148 outlines the contents of the report. Finalized reports must be sent to the radioanalytical laboratory and MAJCOM BE within 30 calendar days of being notified of the possible abnormal exposure.

Investigating potential overexposures

Potential overexposures can either be identified at the installation (worker self-identifies or the IRSO suspects an exposure occurred) or by the radioanalytical laboratory (dosimetry results or bioassay indicates an overexposure may have occurred). An overexposure may represent a potentially or overtly injurious dose of ionizing radiation; therefore, these investigations demand swifter action, more detailed reporting procedures, possible medical follow-up and comprehensive documentation. The following steps are for investigating suspected overexposures:

1. Initiate notifications as required by AFMAN 48-148.
2. Remove the suspected exposed worker from duties.
3. Investigate suspected overexposure.
4. Identify corrective action.
5. Document the investigation.

Initiating notifications

When an IRSO is notified by an individual, or suspects a potential overexposure may have occurred, the IRSO should immediately notify the radioanalytical laboratory, MAJCOM BEE and AFMSA/SG3PB by telephone and follow-up with a facsimile letter explaining the circumstances. This includes, but is not limited to, potential overexposures as a result of accidents or terrorist events, whether in garrison or deployed.

If the radioanalytical laboratory identifies a potential overexposure via a dosimeter or bioassay, they will immediately notify the IRSO by telephone and follow with a facsimile letter within two hours.

Removing the suspected exposed worker from duties

Following any notification of potential exposure, the IRSO immediately contacts the unit commander and requests the individual be removed from all duties involving potential radiation exposure until an investigation of the incident can be completed. The IRSO also notifies the medical treatment facility commander who, in turn, notifies the installation commander.

Investigating the potential overexposure

The radioanalytical laboratory provides facsimile instructions for performing an investigation, to include any bioassay requirements, and requests the IRSO immediately return any dosimeters and/or bioassays in progress at the time to the lab for priority processing. The IRSO investigates suspected overexposures in the same manner as abnormal exposures and considers the same possible root causes.

Documenting the potential overexposure

After completing the investigation, the IRSO must provide a written report of the investigation findings through the MAJCOM BEE to the radioanalytical laboratory within seven calendar days of being notified of the potential overexposure. All reports should contain the information identified in AFMAN 48–125.

Termination of investigation

The radioanalytical laboratory will review reports involving doses considered as a potential or true overexposure. AFMSA/SG3PB evaluates the reports of potential overexposures and either approves termination of the incident or requests additional information. Following termination, the radioanalytical laboratory updates the USAF Master Radiation Exposure Registry, which is a centralized permanent record of exposure for all personnel currently and previously registered in the USAF Ionizing Radiation Dosimetry Program.

638. Performing ionizing radiation calculations

The interaction effects of a radiation field on a mass cannot be measured without defining a meaningful set of radiation *quantities* and *units*. It is important to understand the distinction between *quantity* (the parameter being measured) and a *unit* (the measure of the quantity). Interaction of all kinds of radiation with matter ultimately results in the transfer of energy, through the processes of ionization and excitation already discussed. Radiation calculations are conducted for a variety of reasons, to include (but not limited to) the following:

- Determining the exposure—dose.
- Determining the amount of time personnel can safely be in a radiation area—stay time.
- Determining the amount of time RAM will be harmful—decay.

NOTE: Pervading almost every subject is some form of mathematics. To perform the calculations that follow, a scientific calculator is necessary, as well as familiarity with its functions such as the square key (x^2), square root key ($\sqrt{x}$), exponential key (e^X), and natural logarithm key (LN).

Calculating dose

Dose is the term used to denote the quantity of radiation (energy) being absorbed by a specific mass. The primary concern is how much radiation was absorbed by objects in the environment – most importantly humans. Therefore, dose calculations can be used to estimate the amount of radiation an individual has been exposed.

Recall from the previous unit that there are both conventional and SI units of measurement for D. Additionally, remember from the previous unit that the conventional unit of D is the radiation D (rad). The SI-derived unit of absorbed dose is the Gy which is equivalent to the deposition of 1 J/kg of mass. As such, 1 Gy = 100 rad.

The radiation dose is directly proportional to the time spent in the radiation area. Thus, an individual should never stay near a source of radiation any longer than necessary. Dose calculations are based on actual readings. For example, if a survey meter reads 5 rad per hour (rad/hr) at a particular location, then a total dose of 5 rad (0.05 Gy) will be received if an individual remains at that location for one hour. If they remain at the location for two hours, they will receive a dose of 10 rad (0.1 Gy). The following equation can be used to make simple calculations to determine the dose received in a radiation area.

$$Dose\ (rad\ or\ Gray) = intensity\left(\frac{rad}{hr}\ or\ \frac{Gray}{hr}\right) \times time\ (hrs)$$

<u>Example Problem 1:</u>

<u>Given:</u> SrA Wiley is in an area for 15 minutes and the reading on his survey meter is 10 rad/hr. What dose of radiation did SrA Wiley receive?

<u>Solution:</u> Since the dose rate was given in minutes, first determine the time in hours. Then multiply the reading given by the time in hours to determine the dose rate for the 15-minute exposure.

$$Dose\ (rad\ or\ Gray) = 10\ \frac{rad}{hr} \times \frac{15}{60}\ hr = 2.5\ rad$$

<u>Example Problem 2:</u>

<u>Given</u>: SSgt Prentice is in an area for 10 minutes and the reading on her survey meter is 5 rad/hr. What dose of radiation did she receive?

<u>Solution</u>:

$$Dose\ (rad\ or\ Gray) = 5\ \frac{rad}{hr} \times \frac{10}{60}\ hr = 0.833\ rad$$

Both examples illustrated situations in which actual readings were being reported. The readings were then taken and calculated to determine the total dose each individual received based on a specific exposure time.

Stay time calculations

Safe entry times (stay times) is the amount of time an individual can be exposed to a particular intensity of radiation without exceeding the maximum allowable dose. Typically, stay times and maximum allowable dose are associated with necessary excursions into areas of high radiation to perform critical duties. One possible example would be the amount of time an Airman can work in a BROKEN ARROW site in which a nuclear detonation occurred.

Example Problem 3:

Refer back to Example 2. Consider the possibility that SSgt Prentice needed to stay in the area for longer than 10 minutes but leadership wanted to limit dose to no more than 2.0 rad. Knowing this, how long can she stay in the area?

Solution: Rework the original equation to solve for time.

$$\frac{Dose\ (rad\ or\ Gray)}{intensity\ \left(\frac{rad}{hr}\ or\ \frac{Gray}{hr}\right)} = time\ (hrs)$$

$$\frac{2.0\ rad}{5\ rad/hr} = 0.4\ hrs = 24\ min$$

The calculated dosages should always be considered as approximations. The actual dose may vary. An EPD must be used to determine the actual dosage received by an individual.

Calculating intensity with the inverse square law

The inverse square law states that radiation traveling out from a source is inversely proportional to the square of the distance. This means the dosage decreases at a rate equal to the square of the distance. The inverse square law should be used only when determining hazard distances from a point source since multiple sources will have overlapping dosage areas.

$$I_1 D_1^2 = I_2 D_2^2$$

Where:

I_1 and D_1 are initial intensity (I) and distance (D).
I_2 and D_2 are new intensity and distance.

A very common and highly effective way of reducing exposure is to increase the distance from the radiation source.

Example Problem 4:

Given: A source is producing an intensity of 425 mR/hr at 10 ft from the source. What would be the intensity at 5 ft?

Solution: Start by manipulating the equation to solve for I_2, then substitute.

$$\frac{I_1 D_1^2}{D_2^2} = I_2$$

$$\frac{425\ mR/hr\ (10\ ft)^2}{(5\ ft)^2} = 1700\ mR/hr\ or\ 1.7\ R/hr$$

This example problem was relatively simple because the intensity was given at the first distance to determine the intensity at another given distance. What if a commander wants to know what the distance (in feet) to the 10 mR/hr and 2 mR/hr boundaries?

Example Problem 5:

Given: A source is producing an intensity of 520 mR/hr at 2 ft from the source. What would be the distance in feet to the 10 mR/hr and 2 mR/hr boundaries?

Solution: Start by manipulating the equation to solve for D_2, then substitute.

$$D^2 = \sqrt{\frac{I_1 D_1^2}{I_2}}$$

For the 10 mR/hr distance:

$$D^2 = \sqrt{\frac{(520\ mR/hr)(2\ ft)^2}{10\ mR/hr}} = 14.2\ ft$$

Based on the answer, inform the commander that the 10 mR/hr boundary will be 14.2 ft from the source and using the same process the 2 mR/hr boundary will be 32.2 ft from the source.

Calculating basic fallout dose rate

Calculating fallout decay becomes critical in situations where radiation measurements are taken after an incident to determine when acceptable levels are reached for personnel to resume duty. These are extreme conditions when it is likely that the initial response for personnel will be to shelter in place. With a few simple measurements, radiation intensities can be calculated hours after the incident. The following formula is used for basic fallout decay.

$$\frac{I_1}{t_1^{-1.2}} = \frac{I_2}{t_2^{-1.2}}$$

Where:

I_1 = Radiation intensity at initial time in R/hr.
$t_1^{-1.2}$* = Initial time since the incident in hours.
I_2 = Radiation intensity at second time in R/hr.
$t_2^{-1.2}$* = Second time since the incident in hours.

[**NOTE:** *–1.2 = logarithmic decay factor]

If a nuclear device is detonated, there would be an initial release of radiation—primarily gamma radiation and neutrons. After the initial release, which would likely be over in less than a minute (depending on the yield of device), the basic radiation hazard would be due to residual radiation. This equation allows estimate of the amount of *residual* radiation an individual will be exposed to when entering a radioactively contaminated area after detonation of a device has occurred.

Example Problem 6:

Given: A nuclear device was detonated at 0500 hours and measurements of the fallout showed 120 R/hr at 0800 (3 hours after the burst). Based on this information, what would be the estimated intensity at 1000 hours (5 hours after the burst)?

Solution: Start by manipulating the equation to solve for I_2.

$$\frac{I_1\, t_2^{-1.2}}{t_1^{-1.2}} = I_2$$

$$\frac{120\ R/hr \times (5\ hr)^{-1.2}}{(3\ hr)^{-1.2}} = 65\ R/hr$$

Calculating protection factors

Shielding is one way to protect personnel from exposure to radiation. Generally, the denser or heavier the material, the better shielding it offers. The degree of protection afforded by a fallout shelter is expressed as a “protection factor.” The protection factor is simply the fraction of the available radiation dose that penetrates the shelter and reaches inside compared to the radiation dose rate outside the shelter. To determine a protection factor, simply divide the radiation intensity outside the shelter by the intensity inside the shelter.

$$Protection\,Factor = \frac{Outside\,Intensity}{Inside\,Intensity}$$

Example Problem 7:

Given: Captain Lee measured an outside radiation intensity of 120 R/hr and an inside radiation intensity of 60 R/hr. What is the protection factor?

Solution:

$$Protection\,Factor = \frac{120\ R/hr}{60\ R/hr} = 2$$

Thus, by this illustration, a protection factor of 2 indicates that an individual in the shelter receives one-half of the radiation dose that would be received if unprotected. A protection factor of 100 indicates that only 1/100 or 1 % of the radiation dose reaches those in the shelter.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

628. Bioenvironmental engineering role in the USAF Personnel Dosimetry Program

1. What is a key responsibility of the IRSO concerning the USAF Dosimetry Program?

2. In what situations would BE interact with public health regarding the Dosimetry Program?

629. Types of personal dosimeters

1. If specialty dosimeters such as collar or extremity dosimeters are not worn, what type of dosimeter is worn to determine dose equivalents for the head, lens of the eye, and extremities?

2. What part of a worker’s body is a collar dosimeter used to evaluate exposures?

3. If a worker wears an extremity dosimeter with lead gloves, where is the dosimeter worn?

4. What type of dosimeter is used exclusively by WMD responders?

630. Enrolling and disenrolling personnel

1. What steps must be performed before issuing a TLD?

2. If asked to provide a dosimeter to a one-time user (visitor, student, special study, etc.), what is written on the RDL Listing 1523?

3. If an individual leaves the base without out-processing through BE, what radiation dose is assigned to the individual?

4. List the steps for disenrolling an individual from the Dosimetry Program.

631. Exchanging and shipping dosimeters

1. Most occupational radiation exposure circumstances encountered within the USAF can be adequately monitored at what frequency of exchange?

2. Briefly explain how to assemble a dosimeter.

3. What actions are taken prior to repacking and coordinating shipping of dosimeters back to the RDL?

4. Within how many days after the monitoring period ends must dosimeters be shipped to the USAF RDL, and which squadron or office should handle the shipment?

632. Dosimetry results and histories of occupational exposure to ionizing radiation

1. What must be done with the Listing 1499–1 once it is received in the BE office?

2. If any dose limits are exceeded, what action must be taken and why?

633. Radiation detection equipment

1. How do you check to ensure a scintillator instrument does *not* have any light leaks?

2. When using a GM detector, what is used to prevent alpha and beta from entering the tube?

3. How do you ensure radiation measurements are accurate and will provide meaningful results?

4. What instrument is used to detect alpha radiation during routine workplace surveys and/or response to radiological incidents?

5. When using the Victoreen, how is it configured to measure for beta radiation?

6. What instrument is used to collect air samples to determine the amount of airborne radiological particulates?

634. Performing swipe tests of radiological sources

1. What two types of radiological sources are swipe tested within the AF?

2. How often are sealed sources required to be tested for surface contamination and leakage?

3. When preparing for a swipe sample, how are background readings determined?

4. What is the total surface area covered during a swipe sample on a sealed source material?

635. Surveying radioactive materials for shipment

1. Describe the relationship of the NRC and the DOT with regards to the transportation of RAMs.

2. When monitoring external levels of radiation from a package, at what distance are readings taken from the surface of the package?

3. External surface readings are *not permitted to exceed* what value?

4. What is the total surface area covered during a swipe sample on a package of RAM awaiting shipment?

636. Performing ionizing radiation surveys

1. How often must the inventory of all X-ray producing sources be verified?

2. What are the reasons radiation scatter surveys are performed on medical X-ray units?

3. What type of instrument is used to conduct medical diagnostic X-ray scatter radiation leakage surveys?

4. Why is a one-gallon plastic container filled with H_2O used when taking scatter radiation measurements?

5. Where on the installation will you find the most common application of industrial X-ray units?

6. For NDI unshielded facilities, where should you collect radiation measurements?

7. Why must periodic RAM storage and use surveys be performed?

637. Investigating suspected ionizing radiation overexposures/abnormal exposures

1. Define the terms “abnormal exposure” and “overexposure.”

2. What initial action should be taken if you suspect a dosimeter worn by a worker has received an abnormal exposure?

3. What are the steps for investigating an overexposure?

4. What action *must* the IRSO take after completing an investigation into an overexposure?

638. Performing ionizing radiation calculations

1. What information is needed to determine the dose of radiation a person has received?

2. What is the intensity at 10 ft if the radiation intensity 20 ft from the source is 500 mR/hr?

3. How is the protection factor determined?

Answers to Self-Test Questions

628

1. Maintain ALARA radiation exposures to personnel.
2. To inform them of the scope of the radiation hazards and recommended duty limitations for pregnant workers having exposures to ionizing radiation.

629

1. The whole-body dosimeter.
2. Head and lens of the eye.
3. Under the shielded gloves.
4. The N2.

630

1. (1) Coordinate enrollment information with the USAF RDL.
   (2) Establish the exposure history.
   (3) Brief the wearer on topics specified in AFMAN 48–125.
   (4) Complete the RDL Listing 1523.
2. In the remarks column of RDL Listing 1523, annotate as “one time”.
3. An assigned administrative dose.
4. (1) Determine if the individual wore the dosimeter during the monitoring period.
   (2) Complete the personnel information change form.
   (3) Submit all dosimeters for individual(s) deleted from the program to the USAF RDL at the end of the monitoring period.

631

1. On a quarterly basis.
2. Match each identification label (provided by the USAF RDL) with each TLD holder and hanger as recorded on the RDL Listing 1523. If necessary, make changes to this label, being sure the original print remains legible to properly account for the card and dosimeter. Finally, remove the TLDs from the shipping tray and place each into the properly labeled hanger.
3. Account for all of the dosimeters and disassemble them (remove them from hangers/holders).
4. Dosimeters must be shipped within five workdays after the monitoring period ends through the packing and crating section of the logistics readiness squadron or the commander’s support staff office.

632

1. It must be reviewed, compared to established dose limits, signed by the IRSO indicating the review has taken place and their concurrence with the data on the listing, and a copy of the signed listing is provided to the workplace supervisor.
2. The exposure shall be considered to represent a potential overexposure. Individuals that have possibly received an overexposure will be removed from duties involving radiation exposure pending completion of the final investigation.

633

1. By holding the probe up to a light source and checking the readings.
2. Physical discrimination such as a shield on the detector.
3. Ensure your equipment is properly operated and calibrated.
4. ADM–300 with the AP.
5. By first opening the beta window.
6. RADeCO high volume air sampling kit.

634

1. Sealed and unsealed.
2. Every six months or as specified by the label.
3. By checking the filter paper with an ADM–300 probe or an instrument capable of measuring beta/gamma to establish background readings.
4. Each swipe must cover a 100 cm^2 area.

635

1. The NRC requires RAMs to be shipped IAW the hazardous materials transportation safety regulations prescribed by the DOT.
2. Ten cm or 4 inches from the surface of the package.
3. Ten mrem/hr from any point on the external surface of the unpackaged material or 0.5 mrem/hr at any point around the external surface of the package.
4. Swipe an area of 300 square cm^2.

636

1. Annually.
2. To ensure workers, other patients, and members of the public are not exposed to unnecessary radiation.
3. Ion chamber.
4. To properly recreate the scattering effect that normally takes place during radiographic exposures.
5. At NDI.
6. At locations likely to be occupied by personnel during exposures, like the console, observer location, and offices. Further, take measurements at any access points to the facility. Additionally, it is a good practice to assess potential exposure rates in the unoccupied areas for the purpose of evaluating the maximum hazard potential of the environment.
7. To assess the exposure risk to workers and the general public.

637

1. An abnormal exposure is an exposure received in any monitoring period that is acceptable for that same period but which would result in an overexposure if continued at the same rate. Overexposure is exceeding a regulated exposure standard.
2. Forward the dosimeter to the radioanalytical laboratory together with the control dosimeter and a letter detailing the circumstances involved in the incident.
3. (1) Initiate notifications as required by AFMAN 48-148.
   (2) Remove the suspected exposed worker from duties.
   (3) Investigate suspected overexposure.

(4) Identify corrective action.

(5) Document the investigation.

4. The IRSO provides a written report of the investigation findings through the MAJCOM BEE to the radioanalytical laboratory within seven calendar days of being notified of the potential overexposure.

638

1. The dose rate (intensity) and the exposure time in hours.
2. Two thousand mR/hr or 2.0 R/hr.
3. By dividing the radiation intensity level outside the shelter by the intensity level inside the shelter.

Complete the unit review exercises before going to next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

24. (628) Dosimeters are required to be worn by any workers occupationally exposed to ionizing radiation, especially those who are likely to exceed an external dose of 1 millisievert (mSv), equal to 100 millirem (mrem), or
a. 1 percent of the annual limits of intake (ALI).
b. 2 percent of the ALI.
c. 5 percent of the ALI.
d. 10 percent of the ALI.

25. (628) Who is typically given the responsibility of managing the United States Air Force (USAF) Personnel Dosimetry Program?
a. Bioenvironmental engineering (BE) journeyman.
b. BE senior noncommissioned officer (NCO).
c. Base radiation safety officer (RSO).
d. Public health (PH) craftsman.

26. (628) Who is responsible for enrolling personnel into the dosimetry program and determining the type of external monitoring required?
a. Base safety.
b. Squadron commander.
c. Workplace supervisor.
d. Bioenvironmental engineering (BE).

27. (628) Who interviews the workplace supervisor and enrolled individual when investigating an abnormal exposure to determine its cause?
a. Base ground safety.
b. Installation radiation safety officer (IRSO).
c. Squadron commander and base safety.
d. Major command (MAJCOM) bioenvironmental engineering (BE).

28. (628) The manager of the dosimetry program interacts with which of the following to request priority processing for dosimeters issued to pregnant workers or used in planning special exposures?
a. United States Air Force (USAF) Human Performance Laboratory.
b. Air Force Institute for Operational Health.
c. USAF Radiation Dosimetry Laboratory (RDL).
d. Air Force Research Laboratory.

29. (629) Which dosimeter should be used to evaluate exposures to the head and lens of the eye?
a. Collar.
b. Neutron.
c. Extremity.
d. Whole body.

30. (629) Which type of dosimeter should be issued to individuals who perform fluoroscopic examinations or operate portable medical X-ray equipment?
a. Collar.
b. Neutron.
c. Extremity.
d. Area control.

31. (629) How often do electronic personal dosimeters (EPD) used for first responder or readiness purposes require calibration?
a. Annually.
b. Bi-annually.
c. Once per week.
d. Every 24 months.

32. (629) Emergency response personnel should place the electronic portable dosimeter (EPD) Mk2 on their
a. front torso area, outside of any personal protective equipment (PPE).
b. front torso area, inside of any PPE.
c. collar, outside of any PPE.
d. collar, inside of any PPE.

33. (630) What *must* you do to enroll an individual in the dosimetry program *before* briefing the dosimeter wearer, completing the Radiation Dosimetry Laboratory (RDL) Listing 1523, and issuing the dosimeter?
a. Coordinate with the wing safety office.
b. Obtain medical examination findings.
c. Complete the Radiation Dosimetry Laboratory (RDL) Listing 1499.
d. Establish the exposure history.

34. (630) Which form or listing is used to add an individual to the base radiation dosimetry program?
a. Radiation Dosimetry Laboratory (RDL) Listing 1523.
b. Air Force (AF) Form 2753, Radiological Sampling Form.
c. RDL Listing 1499–1, Occupational Radiation Exposure Report.
d. United States Air Force School of Aerospace Medicine (USAFSAM) Form 1527–1, Annual Report of Individual Occupational Exposure to Ionizing Radiation.

35. (630) To which agency are females responsible to report upon confirmation of pregnancy?
a. Public health (PH).
b. First sergeant.
c. Squadron commander.
d. Primary care manager.

36. (630) What is the *first* step you must do to disenroll an individual from the dosimetry program?
a. Complete Radiation Dosimetry Laboratory (RDL) Listing 1499-1, Occupational Radiation Exposure Report.
b. Submit their dosimeter to the United States Air Force (USAF) Radiation Dosimetry Laboratory.
c. Determine if the individual wore the dosimeter during the monitoring period.
d. Destroy the departing individual's badge in a safe manner.

37. (631) Once dosimeters are collected after the monitoring period and disassembled, the two things that must be compared to account for all issued dosimeters include the thermoluminescent dosimeter (TLD) number and the
a. Radiation Dosimetry Laboratory (RDL) Listing 1523.
b. TLD shipping holder.
c. RDL Listing 1499.
d. shipping document.

38. (632) On which of the following forms/listings is the annual report of individual occupational exposure to ionizing radiation listed?
a. United States Air Force School of Aerospace Medicine (USAFSAM) Form 1527–1, Annual Report of Individual Occupational Exposure to Ionizing Radiation.
b. Radiation Dosimetry Laboratory (RDL) Listing 1523, Dosimetry Assignment Data.
c. Air Force (AF) Form 2753, Radiological Sampling Form.
d. RDL Listing 1499–1, Occupational Radiation Exposure Report.

39. (632) Who sets the value for the investigation action level as part of the as low as reasonably achievable (ALARA) program?
a. Installation radiation safety officer (IRSO).
b. Nuclear Regulatory Commission (NRC).
c. Radioisotope committee (RIC).
d. Installation commander.

40. (632) What should the installation radiation safety officer (IRSO) develop for each dose equivalent category of the Radiation Dosimetry Laboratory (RDL) Listing 1499?
a. As low as reasonably achievable (ALARA) training requirements.
b. Investigation action levels.
c. Maximum exposure rates.
d. Installation activity levels.

41. (633) A common problem you will likely encounter when employing a scintillation instrument that uses a thin window is the
a. tendency to get dirty and provide false measurements.
b. susceptibility to light leaks caused by small holes in the window.
c. textured glass may cause inaccurate readings.
d. susceptibility to cold temperatures that can cause the window to constrict and crack.

42. (633) When using the ADM-300 XP–100, hold the probe
a. parallel to the surface and use a fast and steady sweeping motion.
b. parallel to the surface and use a slow and steady sweeping motion.
c. vertical to the surface and use a fast and steady sweeping motion.
d. vertical to the surface and use a slow and steady sweeping motion.

43. (633) Which radiation measuring device is an example of a gamma-spectrometer?
a. RADiation Detection COmpany (RADeCO) sampler.
b. SAM 940.
c. Geiger-Mueller (GM).
d. Victoreen 451P.

44. (634) What type of testing do you conduct on unsealed radiation sources?
a. Leak.
b. Air.
c. Swipe.
d. Bulk.

45. (634) The most effective means of taking a swipe sample is to
a. add a few drops of deionized water (DI) to dampen it, increasing its efficiency up to 90%.
b. add a few drops of DI to dampen it, increasing its efficiency by 10%.
c. use a dry swipe only, increasing its efficiency up to 90%.
d. use a dry swipe only, increasing its efficiency by 10%.

46. (634) When swipe testing a radiological source, what is the first step after you have prepared and checked the field blank (field paper)?
a. Apply a few drops of deionized (DI) water until the wipe is damp but not soaked.
b. Place a small “X” in pencil on the outer edge of the filter paper on the side to touch the source.
c. In a slow back and forth “S” motion applying moderate pressure, swipe an area of 100 square centimeters (cm^2).
d. Check the filter paper with an ADM 300 with probe or an instrument capable of measuring beta/gamma to establish background reading.

47. (634) What is the total surface area covered, in square centimeters (cm^2), during a swipe sample of a sealed radiological source?
a. 10 square centimeters (cm^2).
b. 30 cm^2.
c. 100 cm^2.
d. 300 cm^2.

48. (635) What type of survey instrument do you use to monitor external radiation levels for packages that contain radioactive material (RAM)?
a. Proportion detector.
b. Portable ion chamber.
c. Scintillation instrument.
d. Geiger-Mueller (GM) detector.

49. (635) When monitoring a radioactive material (RAM) shipment for external levels of radiation, at what distance from the surface of the package are readings taken?
a. 100 centimeters (cm).
b. 50 cm.
c. 20 cm.
d. 10 cm.

50. (636) There is greater concern for public exposure to radiation from medical X-ray operations as compared to industrial X-ray operations because
a. medical X-rays are more harmful than industrial X-rays.
b. industrial X-rays are always conducted in shielded facilities.
c. there are less safety measures to protect the public from medical X-rays.
d. of the proximity of patients and visitors in the medical X-ray environment.

51. (636) The bioenvironmental engineering flight’s (BE) role in the ionizing radiation quality assurance program is to
a. verify the training of all X-ray technicians.
b. evaluate the direct output of X-ray machines.
c. verify that the direct output of X-ray machines has been evaluated.
d. perform scatter surveys on medical X-ray units to ensure all personnel are not exposed to unnecessary radiation.

52. (636) The *easiest* and *most accurate* method you can use to measure ionizing radiation produced by medical X-ray machines is using
a. a portable instrument such as a Geiger-Muller (GM) detector.
b. an electronic portable dosimeter (EPD).
c. thermoluminscent dosimeters (TLD).
d. theoretical worst-case calculations.

53. (636) When conducting medical X-ray machine scatter radiation surveys, you recreate the scatter effect of the radiation by
a. placing a one gallon-plastic container filled with water in line with the beam.
b. placing a one gallon-plastic container filled with sand in line with the beam.
c. placing a specially designed mannequin on the X-ray table.
d. having an X-ray technician lie down on the X-table.

54. (636) Once your radiation storage and use area measurements have been collected in any hour, what criteria in millirem (mrem) are they compared to?
a. 100 mrem.
b. 30 mrem.
c. 10 mrem.
d. 2 mrem.

55. (637) What should be your initial action if you suspect that a dosimeter received an abnormal exposure?
a. Interview the exposed worker.
b. Remove the exposed worker from duties.
c. Send the suspect dosimeter for processing.
d. Take corrective action to prevent further exposure.

56. (637) When investigating an abnormal exposure to ionizing radiation, which action takes place during the *interview the worker* step?
a. Validating the exposure.
b. Identifying corrective action.
c. Determining the portion of the body exposed.
d. Exploring potential causes for the exposure.

57. (637) Within how many days after being notified of a potential overexposure to ionizing radiation *must* a written report be submitted to the Radioanalytical Laboratory?
a. 10 calendar days.
b. 7 calendar days.
c. 10 work days.
d. 7 work days.

58. (638) The scenario that would be a proper time to use the stay time calculation is determining the
a. amount of leak tests a bioenvironmental engineering (BE) technician can safely perform.
b. amount of time a non-destructive inspection (NDI) technician can safely work.
c. amount of time an Airman can work in a BROKEN ARROW site.
d. number of X-rays a technician can safely perform.

Please read the unit menu for unit 3 and continue ➔

Unit 3. Principles of Radiation Protection

639. As low as reasonably achievable training 3–1
640. Ionizing radiation hazard controls 3–2
641. Uses and hazards of depleted uranium 3–8
642. Decay and monitoring of radon gas 3–10
643. Recycling and disposing of radioactive waste 3–13

THANKS TO TODAY'S understanding of radiation and methods of protecting people from ionizing radiation exposure, it is unlikely to have to handle victims of ARS. Therefore, most radiation duties involve minimizing low-level chronic exposures. The aim is to keep exposures ALARA; therefore, there must be standards to follow to know when and what protective measures are needed.

639. As low as reasonably achievable training

ALARA is a radiation safety principle. It is the approach used in radiation protection to manage and control exposures (both individual and collective) to the workforce and to the general public by employing all reasonable methods to keep exposure to a minimum. ALARA is not only a sound safety principle; it is also a regulatory requirement for all radiation safety programs. Radiation safety personnel, as well as users of radiation sources and their senior leadership, are expected to be committed to this concept. An important part of the ALARA concept involves conducting training for all personnel involved in radiological operations. For each job involving exposure to radiation or RAM, workers and their managers are responsible for understanding the job requirements, the radiological hazards and control measures, and ALARA practices.

NOTE: ALARA is *not* a concept used for nonionizing radiation.

Who should receive training

All personnel (military, civilians and in-house contractors) who have the potential to be occupationally exposed to 1 mSv (100 mrem) in a year shall receive initial and annual training that is appropriate in breadth and depth to the radiation hazards present in the workplace; however, other populations may be included based on the judgment of the IRSO. Personnel participating in an intervention must be informed of the potential health risks of their radiation exposure. Further, they must be trained in the necessary principles and procedures to minimize their exposure consistent with training requirements for occupational exposures.

Training content

The IRSO and unit radiation safety officer (URSO), working together, are responsible for ensuring appropriate training is provided. In keeping with the intent of Title 10 CFR 835.103, *Education, Training and Skills*, trainers must possess both technical knowledge (adequate theory, practical knowledge, and experience for the subject matter) and experience, and the developmental and instructional skills required to fulfill their assigned duties.

As a minimum, training should address applicable topics to include the following:

- Types and characteristics of radiation of concern.
- Radioactivity, radioactive decay, or X-ray production (as appropriate).
- Modes of exposure – internal versus external.
- The health risks posed by the exposure.
- General radiation protection principles.
- Use of instruments, equipment, and personal dosimetry, as appropriate.
- Emergency procedures.

- Reporting requirements.
- RAM permit requirements, as appropriate.
- Other occupation specific hazards and the related skills and procedures required for working with RAMs or radiation-producing devices of concern.
- Intrinsic radiation safety training shall be given to all nuclear weapons specialists assigned to nuclear weapons capable units or to units with 91(b) materials within 90 days of assignment and with a refresher given every 15 months thereafter. The IRSO and URSO can expand the scope of this training as appropriate (e.g., handlers, loaders, security forces). The content of training is provided at the AFMSA Radiation Programs web site.

The training program shall be reviewed against the radiological hazards present in the specific work center to ensure training content is appropriate to everyone's assignments and degree of exposure. The training material must be revised as necessary to reflect changes in practices in the workplace. Therefore, consider amending the training in the following areas during the review:

- Radiation dose (dosimetry) results and exposure investigations.
- New procedures and changes to existing procedures.
- New equipment and changes or modifications to existing equipment or facilities.

Documenting training

Training programs presented, course curricula, and attendance must be maintained for a period of five years unless otherwise specified. Training must be documented in each individual's safety and health record.

640. Ionizing radiation hazard controls

Radiation protection guidance is based upon the stochastic concept of biological response mentioned earlier. Because the minimum dose (if any) that causes delayed effects is unknown, the assumption of worst case and the safest course of action (COA) are chosen. Radiation is very beneficial and finds widespread use, so there must be a balance between the advantages and the potential health risks.

Activities that may result in radiation exposure can be broadly divided into two categories: *practices* and *interventions*.

Practices

Routine and controlled operations that incur radiation exposure as an unavoidable aspect of the activity are considered practices. Examples of activities that are considered practices include routine use of radiation emitters or RAMs in medicine, research, industry, and training.

Interventions

Interventions encompass two broad types of activity: activities that are *not* part of controlled practice, such as incident response; and operations necessary to achieve higher objectives, including those of national security, such as military operations. These environments may include deployed locations where known or suspected nuclear or radiological hazards exist, along with radiological environments created by hostile action or nuclear incident or accident.

The application of limits listed in Title 10 CFR 20, *Standards for Protection Against Radiation*, varies depending on whether doses are to the whole body or to only a portion, and whether radiation workers or the general public is involved, and are summarized in the following table.

Annual Dose Limits for Practices[1, 3]				
Application	**Occupational**	**Declared Pregnant Females**	**Minors (16 - 18 years)[4]**	**Public**
Total Effective Dose	50 mSv (5 rem) in a	5 mSv (500 mrem) for	5 mSv (500 mrem)	1 mSv (100 mrem)

Annual Dose Limits for Practices[1, 3]				
Application	**Occupational**	**Declared Pregnant Females**	**Minors (16 - 18 years)[4]**	**Public**
Equivalent[2]. Deep-dose Equivalent + Committed Dose Equivalent.	single year. 500 mSv (50 rem) to any tissue, except lens of the eye.	remainder of pregnancy to the embryo/fetus. (No more than 50 mrem/month is recommended.)	per year. 50 mSv (5 rem) to any tissue, except lens of the eye	in a year[5].
Annual Dose Equivalent				
The lens of eye[6]	150 mSv (15 rem)		15 mSv (1.5 rem)	
The skin[6]	500 mSv (50 rem)		50 mSv (5 rem)	
The hands and feet	500 mSv (50 rem)		50 mSv (5 rem)	

NOTES:

1. Based on the requirements of Title 10 CFR, Part 20.

2. The limits apply to the sum of relevant doses from external exposure in a period of 1 calendar year and the 50-year committed dose from intakes in the same period.

3. The mSv is the preferred unit of dose for radiation protection purposes. Current AF instrumentation uses the Gy or R as their basic unit of measure, and the MRER reports doses in rem. For low LET penetrating radiations (x-rays, gamma rays), the following conversions can be applied: 10 mSv = 1 cSv ~ 1 cGy =10 mGy = 1 rad ~ 1 R.

4. Conditions for Minors: No person under the age of 16 years shall be subjected to occupational exposure, and no person under the age of 18 shall be allowed to work in a restricted area unless supervised, and then only for the purposes of training.

5. In special circumstances, an effective dose of up to 5 mSv in a single year, provided the average over five years does not exceed 1 mSv per year. AFMSA/SG3PB shall be contacted to obtain this variance. Also, general public shall not be exposed to more than 0.02 mSv (2 mrem) in any one hour.

6. Averaged over 1 cm^2, regardless of the area exposed.

Dose limits do not apply for interventions. Instead, the Department of Homeland Security (DHS) and EPA Protective Action Guides (PAG) provide information for operational dose guidance for interventions and operational dose guidance. Information consolidated from these PAGs are shown in the following tables. A commander will use this guidance to balance mission accomplishment with long- and short-term health risks associated with exposure.

DHS and EPA Protective Action Guides		
Phase	**Protective Action**	**Protective Action Guide**
Early	Limit Emergency Worker Exposure	50 mSv (5 rem) (or greater under exceptional circumstances)[1]
	Sheltering of Public	1 to 50 mSv (5 rem) projected dose[2]
	Evacuation of Public	to 50 mSv (5 rem) projected dose[3]
	Administration of Prophylactic Drugs	For potassium iodide, FDA Guidance dose values[4,5,6]
Intermediate	Limit Worker Exposure	50 mSv/yr (5 rem/yr)
	Relocation of Public	20 mSv (2 rem), projected dose first year. Subsequent years: 5 mSv/yr (500 mrem/yr) projected dose
	Food Interdiction	5 mSv/yr (500 mrem/yr) projected dose[7]
	Drinking Water Interdiction	5 mSv/yr (500 mrem/yr) dose
Late	Final Clean-up Actions	Late phase PAG based on optimization

1. In cases when radiation control options are not available or, due to the magnitude of the incident, are not

DHS and EPA Protective Action Guides		
Phase	Protective Action	Protective Action Guide
sufficient, doses above 5 rem may be unavoidable.		
2. Should normally begin at 1 rem; however, sheltering may begin at lower levels if advantageous.		
3. Should normally begin at 1 rem.		
4. Provides protection from radioactive iodine only.		
5. For other information on medical prophylactics and treatment please refer to http://www.fda.gov/cder/drugprepare/default.htm or http://www.bt.cdc.gov/radiation/index/asp or http://www.orau.gov/reacts.		
6. Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies,'' December 2001, Center Drug Evaluation and Research, FDA, HHS (http://www.fda.gov/cder/guidance/5386fnl.htm).		
7. Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies,'' August 13, 1998, Office of Health and Industry Programs, Center for Devices and Radiological Health, FDA, HHS (http://www.fda.gov/cdhr/dmqrp/84.html).		

Operational Dose Guidance			
Total Cumulative Doses[1]	**Radiation Exposure Status Category**	**Recommended Protection and Surveillance Actions[2]**	**Increased Risk of Long Term Fatal Cancer[5]**
0 to 0.5 mSv (0 to 0.05 rad)	0	None	Negligible
0.5 to 5 mGy (0.05 to 0.5 rad)	1A	Record individual dose Initiate periodic environmental monitoring	1:4,000
5 to 50 mGy (0.5 to 5 rad)	1B	Record individual dose Continue monitoring Initiate radiation survey Prioritize tasks Establish dose control measures during operations	1:400
50 to 100 mGy (5 to 10 rad)	1C	Record individual dose Continue monitoring Update radiation survey Continue dose control measures Execute priority tasks only[3]	1:200
100 to 250 mGy (10 to 25 rad)	1D	Record individual dose Continue monitoring Update radiation survey Continue dose control measures Execute critical tasks only[4]	1:80
250 to 750 mGy [6] (25 to 75 rad)	1E	Record individual dose Continue monitoring Update radiation survey Continue dose control measures Execute critical tasks only[4]	1:30
NOTE: Reference AFMAN 10-2503, *Operations in a Chemical, Biological, Radiological, and Nuclear (CBRN) Environment*, for recommended operational exposure guidelines based on the commander's assessment of the mission criticality and acceptable risk level.			
1. The use of the measurement millisievert (mSv) is preferred in all cases. For low LET, whole body irradiation (x - rays, gamma rays): 1 cGy =10 mGy = 1 rad ≈ 10 mSv ≈ 1 R.			
2. All doses should be kept ALARA. This will reduce individual risk as well as retain maximum operational			

Operational Dose Guidance			
Total Cumulative Doses[1]	**Radiation Exposure Status Category**	**Recommended Protection and Surveillance Actions[2]**	**Increased Risk of Long Term Fatal Cancer[5]**
flexibility for future employment of exposed personnel.			
3. Priority missions are those missions that avert danger to people, prevent damage from spreading, or support the organization's mission essential task list (METL).			
4. Critical missions are those missions that are essential to the overall success of a higher headquarters' operation, emergency lifesaving missions, or like missions.			
5. This is in addition to the 1:5 and 1:4 incidence of fatal cancer among the general population. Increased risk is given for induction of fatal cancer. Total lifetime risk is assumed to be 4 – 7% per ~1,000 mSv (100 rad). It must be recognized that higher radiation dose rates produce proportionally more health risks than the same total dose given over longer periods of time.			
6. NATO STANAG 2083, *Commander's Guide on Nuclear Radiation Exposure of Groups*, states 125 cGy (125 rad) as the commander's upper dose limit.			

There are several measures to control exposures to external sources of radiation. However, the three most important measures are the concepts of time, distance, and shielding.

Time in a radiation field

The radiation dose received is directly proportional to the time spent in a radiation field. Therefore, to minimize the dose received, reduce the time spent in the radiation field. Work processes and special tooling can help to reduce time in a radioactive work area.

Here are a few methods for reducing time:

1. Plan and discuss the task prior to entering the area. Use only the number of workers required to do the job.
2. Have all the necessary tools present before entering the area.
3. Use mock-ups and practice runs that duplicate work conditions.
4. Take the most direct route to the job site, if possible and practical.
5. Never loiter in an area controlled for radiological purposes.
6. Work efficiently and swiftly.
7. Perform as much work outside the area as possible or, when practical, remove parts of components to areas with lower dose rates to perform work.
8. In some cases, the radiological control personnel may limit the amount of time a worker may stay in an area due to various reasons. Recall this is the stay time. If assigned a stay time, do not exceed it.

Time protection is as an administrative control. This is one of the least desirable forms of exposure control, but may be necessary as a means of protection when other methods are inadequate or cannot be used, and when the exposure is absolutely necessary to perform a particular task.

Distance from a radioactive source

A very common and extremely effective technique to reduce personnel exposure is to increase the distance from the radiation source. In many instances, this approach is more important than controlling exposure time and can be easily demonstrated for "point" sources of radiation (where the size of the source is very small compared to the distance from it).

While the exposure-time relationship follows a direct dependence (reducing the time spent in a radiation field by one-half reduces the exposure to the individual by one-half), distance dependence from a point source follows the *inverse square law*. Thus, doubling the distance from a point source reduces the exposure by a factor of four. It should be noted that with non-point sources the inverse square law does not apply. In these cases, the relationship between the dose received and the distance from the source does not always follow a simple rule.

The following are a few methods for *maximizing* distance from sources of radiation:

1. Be familiar with radiological conditions in the area.
2. Use remote handling devices when possible.
3. During work delays, move to lower dose rate areas or exit the area completely during long delays.
4. At a minimum, if sources must be handled, keep them at arm's length.

Maintaining distance as a control has aspects of engineering and administrative controls, depending on how it is applied. This is more desirable than just limiting time near a source, but often some sort of shielding as protection from radiation should be used. Because this is a rather involved subject, BE is not involved in designing radiation shields, but must grasp the basics of how and why shielding works. BE personnel must at least be able to determine whether or not someone's plans for a shield will result in an effective shield or if important considerations were overlooked.

Shielding

Shielding is an engineering control. To understand how shielding works, it helps to remember what happens when ionizing radiation interacts with matter-ionization. Energy is required to knock that electron away from its atom. As radiation interacts with the shielding material, ionizations are produced and the radiation loses kinetic energy until eventually it can no longer ionize (with adequate shielding thickness). The choice of the shielding material depends on the type(s) of radiation to be shielded.

Alpha shielding

Alpha particles do not normally present an external radiation hazard which requires shielding. Alpha particles only travel a couple of cm in air and can be stopped by a simple sheet of paper. However, remember that low-energy X-rays and beta particle radiation are often associated with alpha emitters and may create an external hazard when large quantities of alpha emitters are handled.

Beta shielding

Shielding for beta particles alone is easy. Beta particles have a finite range, meaning there is a thickness of material that will completely stop them. Beta particles are effectively shielded by thin layers of metal (such as aluminum) or plastic. It is preferable to use plastic because it is dense enough to stop the electron-sized particle without significant *bremsstrahlung* production.

Keep in mind that bremsstrahlung production is probable with high energy beta emissions. To minimize bremsstrahlung production in beta shielding material, the shielding should be made up of a low atomic number material (such as Lucite, plastics, and/or aluminum). There may be times when a combination of shielding is used; this would consist of a low atomic number shield (such as plastic) first, followed by an outer layer of high atomic number shielding (such as lead). The low atomic number shield absorbs the beta particle energy, while the high atomic shield absorbs the bremsstrahlung photons created by the beta particles interacting with the low atomic number shield.

Photon shielding

As mentioned earlier, shielding for beta particles is easy; however, photons present a different situation. Photon absorption in matter is an exponential process. Theoretically, this means that photons are never completely stopped, no matter how thick the shield. Therefore, the approach in photon shielding is not to completely stop the photons, but to design a shield that can reduce the *intensity* to an acceptable level.

The capability of a material to reduce photon radiation intensity is based on *the linear attenuation coefficient*. This is the probability of interaction per linear distance traveled by the photon. The greater the number of atoms encountered for each cm traveled, the larger the value of the linear attenuation coefficient and the more probable a given type of interaction will occur. The linear attenuation coefficient is the sum of the attenuation coefficients from the photoelectric, Compton scattering, or pair production interactions. The linear attenuation will depend upon the photon energy and the type of material. Photon shielding is dependent on the mass of material (thickness and density) but must also consider the energy of the photon. Shielding for gamma emitters can be established using the characteristic photon energy from the specific radioisotope. Shielding for X-rays, however, is a little more involved. X-rays are usually produced using intentionally induced bremsstrahlung interactions. These photons have a range of energies as a result. X-ray energies are therefore not constant for a typical X-ray beam passing through a shield (fig. 3–1). This factor must be considered when determining shield thickness for X-ray operations.

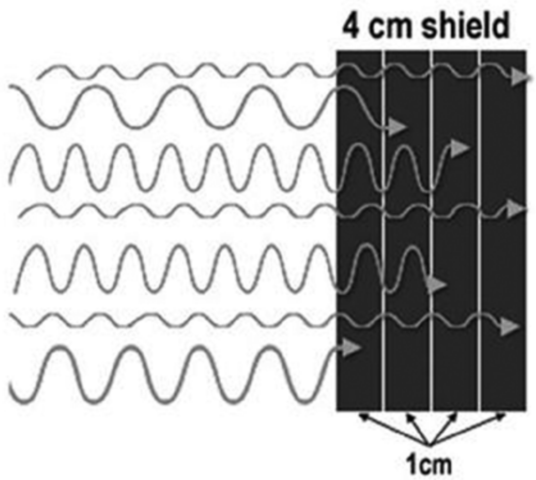

Figure 3–1. X-ray shielding illustration.

Most photon shielding will be high atomic number materials (such as lead or concrete) to maximize the number of photoelectric interactions in the shield. Lead is usually more economical for the lower energy photons, while concrete becomes more economical at very high energies.

N shielding

Shielding for neutrons is very dependent on the neutron energy. While photon shielding was dependent on the mass of material (thickness and density), neutron shielding is dependent mainly on the thickness and type of material, depending on the energy level and anticipated interaction with the shielding material.

Materials with a lot of hydrogen (hydrogenous) such as H_2O and polyethylene are generally good neutron attenuators. Another common neutron shielding material is concrete, which also contains a lot of hydrogen and other low atomic number materials. Borated concrete (concrete with boron added) is also good neutron shielding material. Boron has a high capture cross section (ability to capture through a given thickness) for neutrons.

When energies are below about 5–10 MeV, the hydrogenous shielding material should be placed nearest the neutron source, followed by a high atomic number material to attenuate any hydrogen capture gamma rays produced in the hydrogenous material. At neutron energies greater than 10 MeV, a high atomic number material should be placed closest to the source to degrade the n’s energy spectrum through inelastic scattering. The degraded spectrum is then shielded with hydrogenous material followed by higher atomic number material.

Fortuitous shielding can be used when appropriate. Fortuitous shielding is material placed on an area for reasons other than shielding but acts as a shield because of its location and composition. Steel cabinets, steel security doors, concrete columns, and similar objects can serve as fortuitous shielding. Note that these objects should be permanently mounted if relied on as shielding. Be aware that shielding should be correctly layered for attenuation of different types of radiation (without compromising structure integrity). For example, if a material emits both gamma and strong beta, a layer of plastic might precede a layer of lead, so that beta particles would be captured in the plastic and not produce bremsstrahlung in the lead. Concrete is the best all-purpose shield and should be considered for stopping any type of radiation when space, weight, and cost are not limiting factors. Once the shields are in place, surveys are required to verify that the expected lower intensity is accomplished. Although time, distance, and shielding are considered the most important ways of controlling exposures to radiation, PPE also provides protection in appropriate situations.

Personal protective equipment

Protective clothing prevents contamination on skin and clothing when people must enter contaminated areas. For example, coveralls and gloves will prevent alpha and beta particles from reaching a person’s skin. Respirators can also prevent particulate RAM from entering a person’s respiratory system. When considering protective clothing items for use against ionizing radiation hazards, choices should be based upon the work activity, associated levels of contamination, and whether the contamination is in a dry or wet state. The degree of protection gained by wearing protective clothing depends largely on how the clothing is worn and used by the individual.

641. Uses and hazards of depleted uranium

Uranium is a naturally occurring radioactive element. It is present in nearly all rocks, soils, and air; can be redistributed in the environment through wind and H_2O erosion; and more can be released into the environment through volcanic eruptions. Natural uranium is a mixture of three isotopes: Uranium 238 (U–238), Uranium 235 (U–235) and Uranium 234 (U–234). The most prevalent is U–238, which makes up over 99% of natural uranium. All three isotopes behave the same chemically but have different radioactive properties. The half-lives of uranium isotopes are very long. For example, U–238 is the least radioactive isotope, perhaps resulting in it having the longest half-life, which is 4.5 billion years, which can be seen in the following table.

Radioactive Properties of Uranium Isotopes				
Isotopes	**Half-Life (Years)**	**Natural Abundance (%)**	**Specific Activity (Ci/g)**	**Decay Energy (MeV)**
U-234	248,000	0.0055	6.24×10^{-3}	4.8 alpha (α)
U-235	700 million	0.72	2.2×10^{-6}	4.4 α (0.16 γ)
U-238	4.5 billion	99.27	3.3×10^{-7}	4.2 α

Depleted uranium characteristics

Depleted uranium (DU) is a byproduct of the process used to enrich natural uranium for use in nuclear reactors and in nuclear weapons. It is so-called because the enrichment process results in a waste product or byproduct depleted in both U–235 and U–234. The resultant DU retains a smaller percentage of U–235 and U–234, and a slightly greater percentage of U–238 (99.8% by mass instead of 99.3%). DU is less radioactive than natural uranium.

DU sources and uses

In the US, DU is available mainly from the US Department of Energy (DOE) and other government sources. Because DU metal is almost as hard as steel and 1.7 times denser than lead, it is valuable for many industrial uses. DU occurs in several different compounds with different characteristics, which can have a significant impact on the management and disposition of this material. It has been used for civil and military purposes for many years.

DU is a dense metal known for its use in munitions to penetrate armored vehicles. DU is also used as a counterbalance on helicopter rotors and airplane control surfaces, as a shield to protect against ionizing radiation, and as armor in some parts of military vehicles.

DU potential exposure

Natural and DU that exist in the dust in the air settle onto H_2O, land, and plants. Uranium deposited on land can be reincorporated into soil, washed into surface H_2O, or fastened to plant roots. Uranium in air, surface H_2O, or groundwater can be transported long distances.

The exposure to DU is critically dependent on whether it is external or internal. All three naturally occurring uranium isotopes emit alpha particles as their primary radiation. Because alpha particles cannot penetrate the skin, uranium is usually considered an internal radiological hazard rather than an external radiation hazard.

Food and drinking H_2O are the primary sources of intake for the general public. Root crops such as potatoes, parsnips, turnips, and sweet potatoes contribute the highest amounts of uranium to the diet. Because uranium in soil can stick to these vegetables, the concentrations in these foods are directly related to the concentrations of uranium in the soil where the foods are grown.

In most areas of the US, low levels of uranium are found in the drinking H_2O. Higher levels may be found in areas with elevated levels of naturally occurring uranium in rocks and soil. Very low levels of uranium are found in the air.

People may be exposed to higher levels of uranium if they live near uranium mining, processing, and manufacturing facilities. People may also be exposed if they live near areas where DU weapons have been used.

DU health effects

Most of the uranium you breathe or ingest is not absorbed and leaves the body in the feces. Absorbed uranium is deposited throughout the body (fig. 3–2). The highest levels are found in the bones, liver, and kidneys; for example, 66% of the uranium in the body is found in bones. It can remain in the bones for a long time; the T_b of uranium in bones is 70–200 days. Most of the uranium not absorbed in the bones leaves the body in the urine in 1–2 weeks.

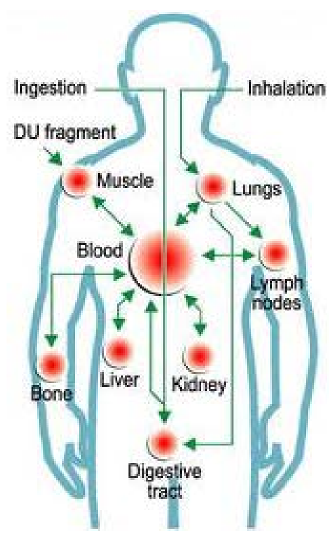

Figure 3–2. Uranium Disposition in the Body.

Chemical risk

DU particles and oxides retained in the body have different solubility. The three uranium oxides of primary concern [uranium dioxide (UO_2), uranium trioxide (UO_3), and triuranium octoxide (U_3O_8)] are relatively insoluble. Insoluble and sparingly soluble uranium compounds are believed to have little potential to cause renal toxicity but could cause pulmonary toxicity through inhalation exposure. The Agency for Toxic Substances and Disease Registry (ATSDR) identifies a "minimal risk" level for intermediate-duration ingestion set at an oral uptake of 2 micrograms (µg) of uranium per kg of body weight per day.

Radiological risk

If inhaled or ingested, DU can produce internal radiation exposure. On average, approximately 90 µg of uranium exists in the human body from natural intake of H_2O, food, and air. The lungs, kidneys, and bone receive the highest annual doses of radiation from uranium, estimated at 1.1, 0.92, and 0.64 mrem, respectively, for US residents. As they decay, DU and its decay products emit alpha, beta, and gamma radiation that can result in external and internal exposure to those who handle or encounter DU-contaminated materials. Based on the zero-threshold linear dose response model, any D of uranium is assumed to result in an increased risk of cancer.

642. Decay and monitoring of radon gas

Radon is a naturally occurring radioactive gas that is odorless and tasteless. It is formed from the radioactive decay of uranium found in small amounts in most rocks and soil. It enters homes and other buildings through small cracks and holes in the foundation. When it is indoors, radon gas becomes trapped and accumulates in the air (fig. 3–3). It slowly breaks down to other products such as radium, which breaks down to radon. Radon also undergoes radioactive decay. The daughter, like radon, is not stable. The dividing of daughters continues until a stable, nonradioactive daughter is formed. During the decay process, alpha, beta, and gamma radiation are released.

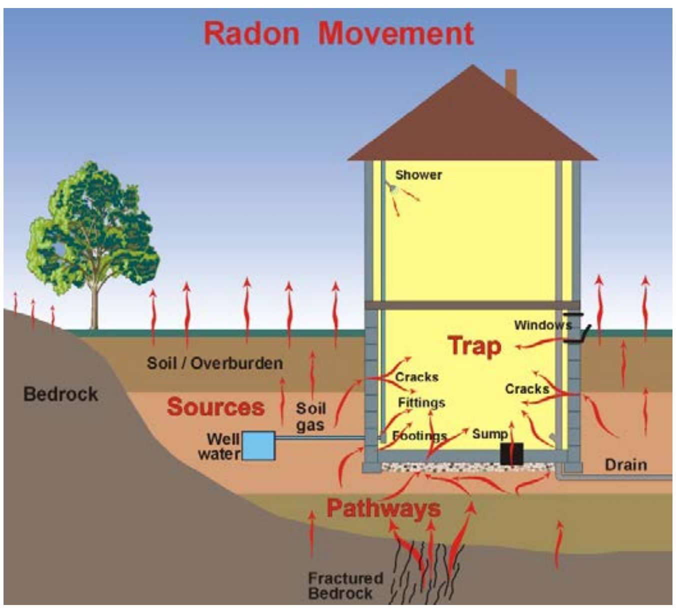

Figure 3–3. Radon movement into and around a home.

Most radon exposure occurs in the home, where people spend the most time. Because radon has no taste, smell, or color, a home must be tested to find out how much radon is in the air. There is no safe level for radon, but the EPA and the surgeon general (SG) recommend addressing issues in homes that have levels at or above 4 picocurie per liter (pCi/L).

Factors impacting radon concentrations in buildings

In addition to having a route of entry, the radon levels in a structure depend on the following:

- The levels of Ra–226 in the soil. Ra–226 is a key factor, because while U–238 is the parent isotope, there are many processes that can change the ratio of U–238 to Ra–226. The ratio of Ra–226 to Rn–222 is relatively constant because of the relatively short half-life of Rn–222.
- Characteristics of the soil. This includes moisture content and permeability.
- Ambient weather conditions. Temperature, wind, precipitation, and barometric pressure are some of the direct impacts of weather. The indirect effects of weather include level of building insulation, ventilation rates, and openness of the building (windows, doors, etc.).
- Pressure-assisted flow. Pressure-assisted flow may occur naturally or due to human activity. An example of natural pressure-assisted flow is the thermal stack effect—the rising and exiting of warm air within a building. Makeup air is pulled into the building through slab and wall imperfections as the warm air rises. The building radon concentration increases when these imperfections are in contact with soil.

Radon health effects

The only documented health effect from exposure to the airborne radon and its decay products are an increased risk of lung cancer. The association between high radon decay product exposures and lung cancer comes from epidemiological studies of uranium miners. The miners that were chronically exposed to very high levels of radon and radon decay products experienced a much higher incidence of lung cancer. Figure 3–4 shows how radon gas affects humans. The risk of cancer due to radon exposure is increased for smokers, as the radiation emitted by tobacco synergizes when in the presence of radon gas.

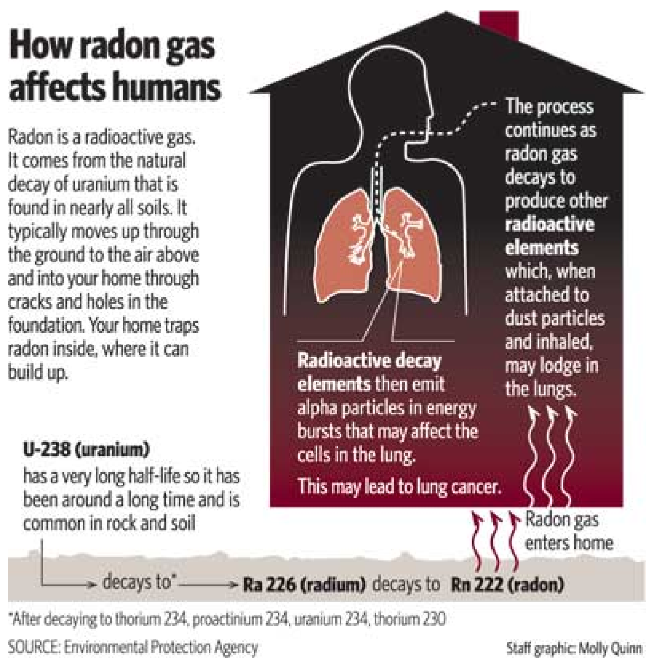

Figure 3–4. How radon gas affects humans.

Radon uses

Radon has been used in the treatment of various diseases including cancer, arthritis, diabetes, and ulcers, but these procedures have been stopped. Radon is used to predict earthquakes, in the study of atmospheric transport, and in exploration for petroleum and uranium. The primary source of concern for radon exposure is from natural environmental uranium decomposition; this is especially the case when radon gas leaks into unventilated structures, particularly in unventilated basements.

Radon regulatory requirements

There are no legally enforceable, general population exposure standards for radon. There are occupational exposure standards for radon and radon decay products, but these are not applicable to natural sources of radon or to environmental (non occupational) exposures. This does not mean it is not necessary to protect workers and the base population from the hazards of radon gas.

Recommended radon exposure limits

Radon has always been regulated in the mining industry, especially at uranium mines. Concern over radon in occupied structures was raised by a 1984 incident in which a nuclear power plant worker tripped radiation alarms on the way into the facility. The investigation that followed found the source of the high readings was the extremely high radon levels in the worker's home.

The subsequent EPA investigation determined that the problem was not limited to one area, which prompted the EPA to develop guidance for indoor radon concentration. The national program was initiated by the Indoor Radon Abatement Act (IRAA) of 1988 (Public Law 100–551, Sections 307 and 309). This law directed the EPA to identify areas of the US and its territories that have the potential to produce harmful levels of indoor radon.

The Occupational Safety and Health Administration (OSHA) has regulations that apply to employee exposures to radon and require employers to test the workplace environment. The OSHA requirement does not apply to the public. OSHA has opted to adopt the NRC standard for the workplace, which is 30 pCi/L with the radon progeny present. The 30 pCi/L value is based on being exposed at this level for a 40-hour work week for 1 year. In any such period where the number of hours of exposure is less than 40, the limits specified in the table may be increased proportionately. In any such period where the number of hours of exposure is greater than 40, the limits specified in the table shall be decreased proportionately. The OSHA occupational limit is higher than the EPA action levels (AL).

Since most USAF personnel are not classified as radiation workers, the limits found in EPA guidance apply. The EPA publication titled *A Citizen's Guide to Radon* provides a good deal of information and states the following:

- Homeowners should mitigate their homes if the radon level is 4 pCi/L or greater.
- Homeowners should consider mitigation if the levels are between 2 pCi/L and 4 pCi/L.

Bioenvironmental Engineering role with radon

In anticipation of the IRAA, the AF initiated its Radon Assessment and Mitigation Program (RAMP) in October 1987. The initial RAMP was conducted in three phases. Phase I, the screening phase, was designed to prioritize the radon risk on each base. Phase I resulted in the prioritization of each base as high, medium, or low radon risk.

- High Risk. Bases with known elevated radon potential ≥20 pCi/L (e.g., very elevated radon levels confirmed in one or more rooms).
- Medium Risk. Bases with radon potential >4 pCi/L but ≤20 pCi/L (e.g., elevated radon levels confirmed in one or more locations).
- Low Risk. Bases with radon potential of ≤4 pCi/L; these were excluded from further surveys and did not require mitigation.

NOTE: A list of AF prioritizations of bases is available in the *Bioenvironmental Engineer's Guidebook to Ionizing Radiation*, dated September 2013, which can be obtained at https://apps.dtic.mil/dtic/tr/fulltext/u2/a439547.pdf.

Phase II, the detailed assessment phase, was designed to survey the radon levels in each testable building (ground contact buildings). Phase III, radon remediation and confirmation testing, was designed to conduct the remediation needed to reduce the radon concentrations below guidance levels. The base BE was responsible for Phases I and II. The base civil engineer (CE) was responsible for the remediation required in Phase III, while the base BE was responsible for conducting the measurements needed to verify the effectiveness of the Phase III remediation. Phase III required the remediation of all structures that exceeded guideline levels IAW the timelines in the following table.

Radon Level (pCi/L)	Mitigation Timeframe (RAMP, 1987)
≥ 200.	Immediate mitigation or removal of occupants until mitigation can be accomplished.
≥ 20 but < 200.	Within 6 months.
≥ 8 but < 20.	Within 1–3 years.
≥ 4 but < 8.	Within 3–5 years.
< 4.	Mitigation not required.

If all phases of the radon assessment and mitigation have been completed, the BE involvement with radon will be minimal. Unfortunately, there are too many incidents where the process was not completed. BEs must now comply with requirements outlined in AFMAN 48–148, *Ionizing Radiation Protection* and the *Bioenvironmental Engineer's Guidebook to Ionizing Radiation.*

643. Recycling and disposing of radioactive waste

Any activity that uses RAM may produce radioactive waste. All radioactive waste must be handled in the proper manner to ensure the safety and health of the general public and the protection of the environment. Within the AF, the daily management of RAM, including waste, is governed by AFMAN 40-201. This publication implements the federal regulations governing RAM.

The Air Force Radioactive Recycle and Disposal (AFRRAD) office, permitted under the AF MML, recycles and disposes of both radioactive and mixed waste generated by AF operations. Mixed waste is waste that contains both a Resource Conservation and Recovery Act hazardous component and a radioactive component. Much of the radioactive waste comes from products used every day. The following are common items handled by AFRRAD:

1. Smoke detectors that contain small amounts of the isotope Americium–241.
2. Watches, compasses, and self-illuminating exit signs that often contain tritium (a radioactive isotope of hydrogen).
3. Radium dials from old aircraft that illuminate at night.

The IRSO coordinates recycling and disposal requests at the installation level. Requests are initiated through the AFRRAD web site by completing a "*Request/Disposal Request for Services.*" AFRRAD determines whether the material is waste or is recyclable based on the description of the material and provides disposition instructions. Disposition instructions will include specific packaging, labeling, and shipping requirements. Shipments of radioactive waste must meet all DOT regulations. On rare occasions, it may be deemed outside the ability of the installation to ship wastes. In this case, people from AFRRAD will travel to the installation to handle the recycling and/or disposal request in person.

Radioactive waste should be disposed as soon as practical. Collection or storage of radioactive wastes should not exceed one year. While awaiting disposal instructions from AFRRAD, the radioactive waste must be stored according to permit requirements in an enclosed, secure facility with access limited to authorized personnel only.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

639. As low as reasonably achievable training

1. Describe how the ALARA principle applies to radiation protection.

2. Who should receive ALARA training?

3. List the topics that should be covered when conducting ALARA training.

640. Ionizing radiation hazard controls

1. Since we *do not* know the *minimum* dose of radiation that can cause delayed effects, what approach is taken with regards to radiation protection?

2. What effective dose limit is established for occupational exposures (both internal and external) to the whole body in a single year?

3. Cite the three *most* important measures related to controlling exposures to external sources of ionizing radiation?

4. What type of control is time protection?

5. Define the principle of the inverse square law as it applies to distance from a radioactive source?

6. What type of control is shielding?

7. Describe how shielding works to provide protection against ionizing radiation?

641. Uses and hazards of depleted uranium

1. What type of radiation particles is primarily emitted by all three naturally occurring uranium isotopes?

2. What is the primary source for DU intake by the general public?

3. What parts of the body absorb most of the DU once it is ingested or inhaled?

642. Decay and monitoring of radon gas

1. What types of radiation does radon release as it decays?

2. What disease has the only documented increased risk from exposure to airborne radon and its decay products?

3. Which type of natural disaster is radon used to predict?

643. Recycling and disposing of radioactive waste

1. What AFI provides guidance on the daily management of RAM?

2. What office is responsible for issues relating to the recycling and disposal of radioactive waste within the AF?

3. Who is responsible for coordinating recycle and disposal requests at the installation level?

4. What do disposition instructions from the AFRRAD office include?

5. How *must* radioactive waste be stored while awaiting disposal instructions from the AFRRAD office?

Answers to Self-Test Questions

639

1. ALARA is the approach used in radiation protection to manage and control exposures (both individual and collective) to the workforce and to the general public by employing all reasonable methods to keep exposure to a minimum.
2. All personnel (military, civilians and in-house contractors) who have the potential to be occupationally exposed to 1 mSv (100 mrem) in a year.
3. Training should include the following:
   - Types and characteristics of radiation of concern.
   - Radioactivity, radioactive decay, or X-ray production (as appropriate).
   - Modes of exposure - internal versus external.
   - The health risks posed by the exposure.
   - General radiation protection principles.
   - Use of instruments, equipment, and personal dosimetry, as appropriate.
   - Emergency procedures.
   - Reporting requirements.
   - RAM permit requirements, as appropriate.
   - Other occupation specific hazards and the related skills and procedures required for working with RAMs or radiation-producing devices of concern.
   - Intrinsic radiation safety training shall be given to all nuclear weapons specialists.

640

1. Assume the worst case and choose the safest COA.
2. 50 mSv (5 rem).
3. Time, distance, and shielding.
4. Administrative.
5. Doubling the distance from a point source reduces the exposure by a factor of 4.
6. Engineering.
7. As radiation interacts with the shielding material, ionizations are produced and the radiation loses kinetic energy.

641

1. Alpha.
2. Food and drinking H_2O.
3. In the bones, liver, and kidneys; 66% is absorbed within the bones.

642

1. Alpha, beta and gamma.
2. Lung cancer.
3. Earthquakes.

643

1. AFMAN 40-201.
2. AFRRAD.
3. The IRSO.
4. Specific packaging, labeling, and shipping requirements.
5. According to permit requirements in an enclosed, secure facility with access limited to authorized personnel only.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

59. (639) What approach does the Air Force (AF) use to manage and control ionizing radiation exposures to the workforce and to the general public by employing methods to keep exposure to a minimum?
a. Eliminate all exposures.
b. As low as can be achieved.
c. Eliminate unsafe exposures.
d. As low as reasonably achievable.

60. (640) The inverse square law regarding a person's exposure to radiation has such an effect that moving away
a. double the distance from a point source reduces the exposure by a factor of 4.
b. double the distance from a point source reduces the exposure by a factor of 2.
c. 1/2 the distance from a point source reduces the exposure by a factor of 1/2.
d. 1/3 distance from a point source reduces the exposure by a factor of 1/3.

61. (640) Coveralls and gloves will prevent what type of radiation from potentially harming a person's skin?
a. Photon.
b. Neutron.
c. Alpha and beta.
d. Gamma (**γ**) and X-ray.

62. (641) The *primary* source for depleted uranium intake by the general public is
a. transport aircraft.
b. food and drinking water.
c. uranium mining facilities.
d. areas where depleted uranium munitions have been used.

63. (641) As it decays, depleted uranium particles emit which type(s) of radiation?
a. Alpha.
b. Gamma (**γ**).
c. Alpha and beta.
d. Alpha, beta, and gamma.

64. (642) As it decays, radon gas emits which type(s) of radiation?
a. Alpha.
b. Gamma (**γ**).
c. Alpha and beta.
d. Alpha, beta and gamma.

65. (642) The only documented health effect from exposure to the airborne radon and its decay products are an increased risk of
a. emphysema.
b. lung cancer.
c. pancreatic cancer.
d. thyroid nodular disease.

66. (643) What section recycles and disposes of radioactive waste and mixed waste generated by Air Force (AF) operations?
a. United States Air Force School of Aerospace Medicine (USAFSAM) Radioanalytical Laboratory.
b. Air Force Radioactive Recycle and Disposal (AFRRAD) office.
c. Nuclear Regulatory Commission (NRC).
d. Air Force Medical Support Agency.

67. (643) Who on your base coordinates recycling and disposal requests for radioactive waste?
a. Defense Reutilization and Marketing Service.
b. Installation radiation safety officer (IRSO).
c. Environmental management.
d. Wing safety office.

Please read the unit menu for unit 4 and continue ➔

Student Notes

Unit 4. Nuclear Enterprise

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ON 16 JULY 1945, the world changed with the explosion of the first atomic bomb. The explosion took place at Trinity Site which is on what is now White Sands Missile Range. The first atomic bomb was tested at 5:29:45 a.m. Mountain War Time. The 20–22 kiloton explosion not only led to a quick end to the war in the Pacific but also ushered the world into the atomic age. All life on Earth has been touched by the event that took place at the Trinity site.

The story of Trinity Site begins with the formation of the Manhattan Project in June 1942. The project was given overall responsibility of designing and building an atomic bomb. At the time it was a race to beat the Germans who, according to intelligence reports, were building their own atomic bomb.

Three large facilities were constructed to accommodate the Manhattan Project. At Oak Ridge, Tennessee, huge gas diffusion and electromagnetic process plants were built to separate uranium 235 from its more common form, uranium 238. Hanford, Washington became the home for nuclear reactors, which produced a new element called plutonium (Pu). Both uranium 235 and plutonium are fissionable and can be used to produce an atomic explosion.

Los Alamos was established in northern New Mexico to design and build the bomb. At Los Alamos, many of the greatest scientific minds of the day labored over the theory and actual construction of the device. The group was led by Dr. J. Robert Oppenheimer who is credited with being the driving force behind building a workable bomb by the end of World War II.

At the end of the Cold War, significant changes in the global security environment prompted AF senior leaders to restructure the force. Anticipating and adapting to global challenges, commanders at all levels shaped the combat forces under their control through several initiatives. During that time, the AF and other services were experiencing severe resource constraints. With less national emphasis on nuclear weapons during this period, the AF failed to grasp the continued need to maintain a viable airpower-based nuclear deterrent capability. Moreover, as the size of the nuclear arsenal was reduced and emphasis shifted to conventional missions, the AF failed to articulate the continuing value of the nuclear deterrent.

In 2006, critical, nuclear-related intercontinental ballistic missiles (ICBM) parts, labeled as helicopter batteries, were mistakenly sent to Taiwan. In 2007, a B–52 crew mistakenly flew six nuclear weapons from Minot AFB, North Dakota to Barksdale AFB, Louisiana. These incidents triggered a series of reviews and investigations ordered by the secretary of defense (SecDef) and the secretary of the Air Force (SAF). As a result of these investigations the Air Force Nuclear Task Force prepared the 2008 report, *Reinvigorating the Air Force Nuclear Enterprise*, made available at the web site https://fas.org/irp/doddir/usaf/nuclear.pdf.

The primary cause of the systemic breakdowns in the AF's nuclear enterprise was the failure of leadership at many levels to provide proper emphasis on the nuclear mission. The loss of focus stemmed from changes in the operating environment at the end of the Cold War, exacerbated by the profound changes in the security environment following the terrorist attacks against America on September 11, 2001 (known as 9/11). In 1992, the AF implemented the largest organizational change since its inception leading to the *organizational and supervisory fragmentation of the nuclear enterprise.* This was reinforced by the 1995 Base Realignment and Closure decisions that dispersed depot support for nuclear systems and components. As a result, the AF's nuclear sustainment system became fragmented, the pool of nuclear experienced Airmen atrophied, and nuclear expertise eroded as less time was allocated to maintain nuclear operational proficiency. The AF failed to properly resource many nuclear mission areas, effectively relegating the AF's nuclear enterprise to a "care-taker" status with limited modernization or recapitalization. The Global War on Terrorism (GWOT) and Operation ENDURING FREEDOM (OEF) and Operation IRAQI FREEDOM (OIF) further shifted focus and institutional priorities away from the nuclear mission. Subsequently, AF leadership failed to advocate, oversee, and properly emphasize the maintenance of nuclear-related skill sets. Deficiencies in inspection processes also contributed to the erosion of the culture of accountability and rigorous self-assessment associated with high standards of excellence.

Assessments of the AF nuclear enterprise raised concerns about the quantity of nuclear experts, depth of the nuclear expertise, and quality of AF processes for building expertise. Both training and education in nuclear matters were streamlined to the point of near elimination. In response, the AF instituted a broad range of initiatives to reverse this trend, which included curriculum revisions for technical training and professional military education.

Rebuilding of the nuclear enterprise is imperative; first, the institutional, long-term commitment to the nuclear deterrence mission must be addressed. The nuclear culture of discipline and accountability must be re-established, pride in mission must be re-kindled, and a heritage of excellence must be renewed as the AF nuclear enterprise is reinvigorated. Today, more countries possess nuclear weapons than did during the Cold War, and that number is likely to grow. While faced with many security challenges during the Cold War, over time, the AF came to understand the motivations and the likely responses of the single adversary that could do catastrophic harm to the US and our allies. Today, there are national and transnational adversaries with motivations and responses that are perhaps less predictable and have potential to do great harm to the US or our allies.

Nuclear forces continue to represent the ultimate deterrence capability that supports US national security. Because of their immense destructive power, nuclear weapons, as recognized in the 2006 National Security Strategy, deter in a way that simply cannot be duplicated by other weapons. Additionally, the special nature of nuclear weapons demands precise performance across the AF nuclear enterprise, with no tolerance for complacency or shortcuts. In short, the AF will continue to fortify current operations, develop people, and sustain and modernize current capabilities.

Credible strategic deterrence, with unwavering commitment to nuclear deterrence as its cornerstone, is foundational to the security of our nation, allies, and friends. The roadmap is the strategic plan to ensure day-to-day excellence in the stewardship of nuclear deterrence capability, mission, and enterprise. These changes will be institutionalized across the nuclear enterprise ensuring commitment to excellence regardless of changes to force structure, competing mission requirements, or the size of the nuclear arsenal. The hallmarks of performance standards, when it comes to the nuclear deterrence mission, are precision and reliability. A culture of compliance, clear organizational structures, and active governance processes are the principal pillars to achieve sustained excellence in this most vital mission area.

A composite structure of sustainment, operational, and Headquarters Air Force (HAF) organizations that are appropriately resourced with focused processes to ensure safe, secure, reliable operations must be built. Current and future capability, advocacy, and a culture of compliance; institutional focus; accountability/oversight; and governance of these activities—a principal focus of this roadmap must be enabled.

644. Theory and operation of nuclear weapons

Credible nuclear deterrence is essential to security. Many allied and friendly countries continue to depend on the security umbrella provided by the nuclear deterrence capability of the US. In the absence of this "security umbrella," some non-nuclear allies might perceive a need to develop and deploy their own nuclear capability. Geopolitical events underscore the necessity for extended deterrence.

Nuclear weapons delivery platforms

There are three global delivery platforms for nuclear weapons: ICBMs, *bombers*, and *submarine-launched ballistic missiles* (SLBM), as pictured in figure 4–1. They are maintained by the United States Air Force (USAF) and Navy, while their nuclear operational use is controlled by US Strategic Command (USSTRATCOM). Each has its advantages and limitations. By maintaining the *Triad* of forces (fig. 4–1), the limitations of each are balanced by the other systems and their vulnerability to attack is lessened. ICBMs, bombers, and SLBMs comprise a system that allows for a nuclear option regardless of the method of attack used by an enemy.

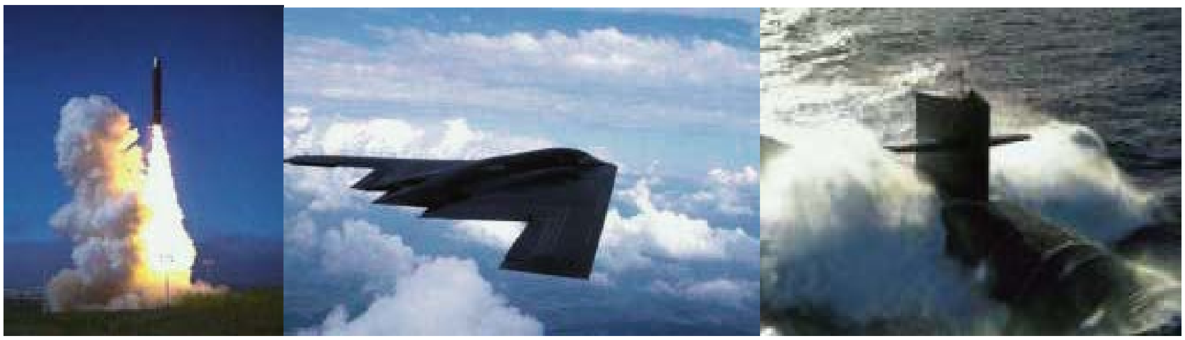

Figure 4–1. Global delivery platforms.

Intercontinental ballistic missiles

ICBMs can hold time-urgent targets at risk and can be rapidly retargeted against mobile and emerging targets. They maintain a high alert rate and can be quickly launched once an execution order is received. Their hardened launch facilities afford them a chance for survival if attacked. They have a high degree of accuracy, giving them the ability to destroy hardened targets. Among their shortcomings is the fact that their locations cannot be kept secret, making it very easy for an enemy to target them. Further, once launched, ICBMs cannot be recalled or destroyed, making it difficult to use them for posturing.

Bombers

AF bombers may be used to carry nuclear gravity bombs or nuclear-armed air-launched cruise missiles or advanced cruise missiles. These aircraft can be used effectively to send a message of American resolve to an adversary. Various stages of alert, from generating the bomber force to launching aircraft, may be observed by a potential enemy and serve as notice that the US is prepared to respond to an attack. Tanker aircraft, many of which are flown by the Air Reserve Component (ARC), provide bombers both extended range and the flexibility to be redirected and hold a variety of targets at risk, including mobile targets. However, the time required for them to reach their targets can limit their effectiveness. In addition, they are "soft" targets and are vulnerable on the ground, which means that tactical warning is essential if they are to remain a viable option. Dispersing the bomber and tanker force to other airfields or assuming an airborne alert posture can enhance survivability.

Submarine-launched ballistic missiles

The Navy's SLBMs are closely integrated with AF nuclear platforms to maximize the effectiveness of the Triad. These systems have the advantage of operating from hidden locations and can be close enough to an enemy to deny significant warning of an attack. Submarines in port can be used to signal American resolve as they surge out to sea, but that is the extent of the posturing for which submarines can be used. The submarines have historically suffered from other limitations as well. They carried missiles that were not as accurate as ICBMs, limiting their effectiveness against hardened targets, and it was difficult to communicate with them. However, advances in both weapons and communications technologies have reduced the impact of these shortcomings.

The AF provides two of the three critical legs of the nation's nuclear deterrent forces. Flexible AF bombers and forward-based, dual-capable aircraft (DCA) fighter's best exploit the political element of nuclear weapons by being able to visibly demonstrate resolve or the potential for escalation through the scalable generation of forces and recallable airborne alert postures. Ready, capable, and secure ICBMs provide the unique, sovereign-based, stabilizing, and responsive capability to hold any target on the globe at risk 24/7.

Definition of Air Force nuclear enterprise

The AF nuclear enterprise consists of the people, organizations, processes, procedures, and systems used to conduct, execute, and support nuclear operations and forces. It includes the infrastructure and life-cycle activities for nuclear weapons, delivery platforms, and supporting systems; intellectual and technical competencies; and cultural mindset that ensure sustainable, responsive, safe, reliable, and secure AF nuclear deterrence capabilities. In addition, it includes AF organizations responsible for nuclear policy and guidance, and AF relationships with other entities who contribute to the Nation's nuclear deterrence mission.

Nuclear weapons, along with the operations, support, maintenance, infrastructure, and security associated with them, are a unique national capability. The destructive power of nuclear weapons and their political effects places them under the direct control of the president. Nuclear operations are the linchpin of strategic deterrence. Their flexibility provides latitude to the president in which to make decisions; whether to exercise escalation control measures, demonstrate resolve, negotiate with authority, assure friends and allies, ensure US national security against disruptive technological challenges, and defeat adversaries with prompt, overwhelming force.

The probability of a chemical, biological, radiological, and/or nuclear (CBRN) attack against the US or its interests has increased since the end of the Cold War. Rogue nation-states and terrorist groups seeking to develop and/or acquire WMDs are enabled and motivated by technology transfers, surrogate resourcing, misplaced phobias, and posturing for attention within the international community. The US, its allies, and like- minded nations, fully aware of the growing threat, must determine how to deter such attacks and protect their interests. To this end, the strategic deterrence provided by the US nuclear enterprise is vital in preventing the proliferation of WMD by our allies and its use by our enemies.

A nuclear weapon accident or incident (whether accidental or intentional) is different from other accidents due to the possibility of radioactive contamination at the immediate site and extending beyond the controlled area. The complexities of a nuclear weapon accident or incident are compounded further by general lack of public understanding of radiological hazards. The incident commander (IC) must quickly establish a vigorous and comprehensive health physics and industrial hygiene/safety program to manage the health and safety aspects of a nuclear weapons accident or incident. A good health and safety program provides for civil official involvement in the cooperative development of response efforts and a site remediation plan.

One of the fundamental differences between a nuclear and a conventional explosion is that nuclear explosions can be many thousands (or millions) of times more powerful than the largest conventional detonations. Both types of weapons rely on the destructive force of the blast or shock wave. However, the temperatures reached in a nuclear explosion are very much higher than in a conventional explosion, and a large proportion of the energy in a nuclear explosion is emitted in the form of light and heat. This energy is capable of causing skin burns and of starting fires at considerable distances. Nuclear explosions are also accompanied by various forms of radiation, lasting a few seconds to remaining dangerous over an extended period of time.

Fission and fusion of nuclear materials

A *nuclear weapon* derives its destructive force from the nuclear reaction of *fission*, *fusion*, or a *combination* of fission and fusion. Nuclear weapons are considered the most destructive manmade force on this planet.

Fission can occur when the nucleus of a heavy atom captures a neutron, or it can happen spontaneously. When a nucleus undergoes fission, it splits into several smaller fragments and two or three neutrons (fig. 4–2).

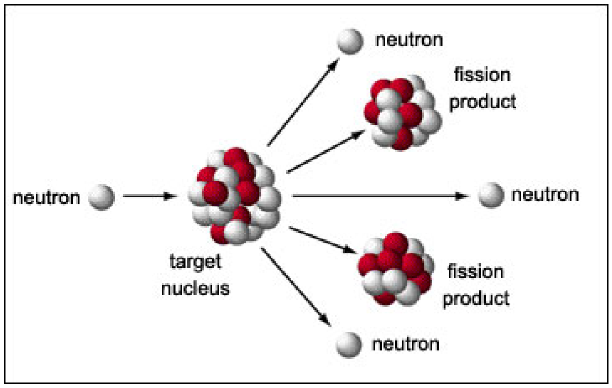

Figure 4–2. Nuclear Fission.

The sum of the masses of these fragments is less than the original mass. This "missing" mass (about 0.1% of the original mass) has been converted into energy according to Einstein's equation ($E=mc^2$). In this case, the equivalent energy (E) is calculated by the mass multiplied by the speed of light (c) squared.

Nuclear chain reactions

A chain reaction refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus. This nucleus in turn produces neutrons, and the process repeats. The process may be controlled (nuclear power) or uncontrolled (nuclear weapons). If each neutron releases two more neutrons, then the number of fissions can double each generation (fig. 4–3). In that case, in 10 generations there are 1,024 fissions; in 80 generations, there are approximately 6×10^{23} (a mole) fissions.

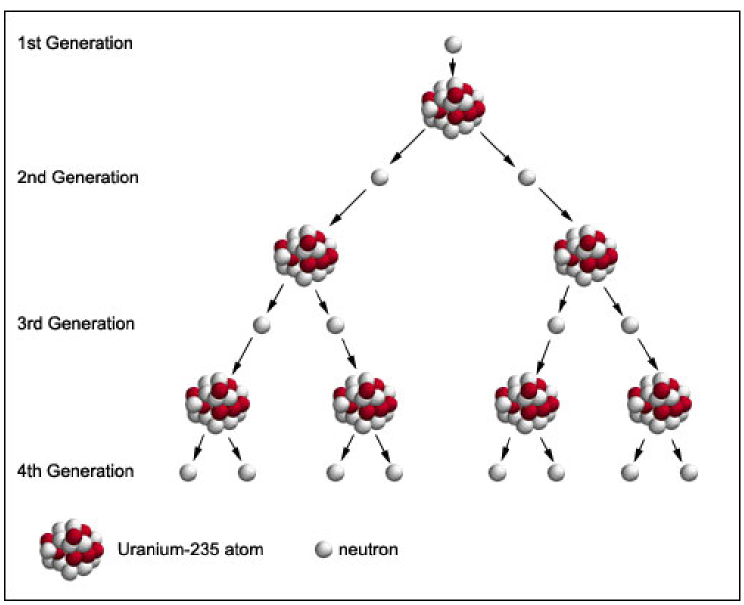

Figure 4–3. $^{235}U + n \rightarrow$ fission + 2 or 3 n + 200 MeV.

Critical mass

Although two to three neutrons are produced for each fission, not all these neutrons are available for continuing the fission reaction. If the conditions are such that the neutrons are lost at a faster rate than they are formed by fission, the chain reaction will not be self-sustaining. The point where the chain reaction can become self-sustaining is referred to as critical mass.

In an atomic bomb, a mass of fissile material greater than the critical mass must be assembled instantaneously and held together for about a millionth of a second to permit the chain reaction to propagate before the bomb explodes.

The amount of a fissionable material's critical mass depends on several factors. These include the shape of the material, its composition and density, and the level of purity. A sphere has the minimum possible surface area for a given mass, and hence minimizes the leakage of neutrons. By surrounding the fissionable material with a suitable neutron "reflector," the loss of neutrons can be reduced, as well as the critical mass.

Controlled nuclear fission

To maintain a sustained controlled nuclear reaction, for every 2 or 3 neutrons released, only one must be allowed to strike another uranium nucleus (fig. 4–4). If this ratio is less than one then the reaction will die out; if it is greater than one it will grow uncontrolled (an atomic explosion). A neutron-absorbing element must be present to control the amount of free neutrons in the reaction space. Most reactors are controlled by means of control rods that are made of a strongly neutron-absorbent material such as boron or cadmium.

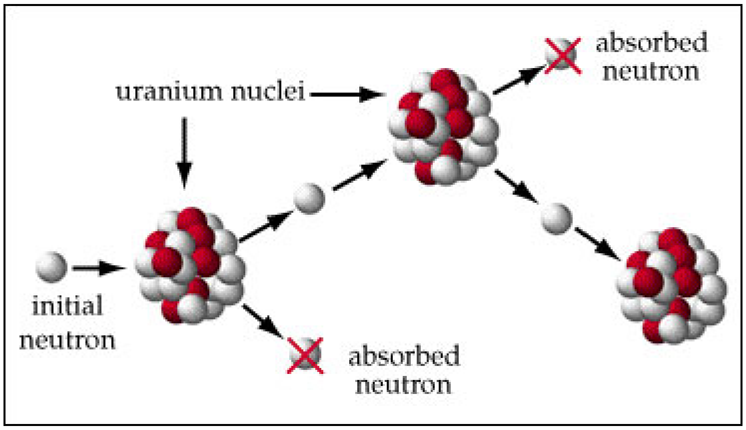

Figure 4–4. Sustained Controlled Nuclear Reaction.

In addition to the need for *capturing* neutrons, the neutrons often have too much kinetic energy. These *fast neutrons* are slowed by a moderator such as heavy H_2O (deuterium substituted for hydrogen in the molecule) and ordinary H_2O. Some reactors use graphite as a moderator, but this design has several problems. Once the fast neutrons have been slowed, they are more likely to produce further nuclear fissions or be absorbed by the control rod.

Why uranium and plutonium?

The most common isotope, uranium 238, is not suitable for developing a nuclear weapon. There is a fairly high probability that an incident neutron would be captured to form uranium 239 instead of causing a fission. However, uranium 235 has a high fission probability.

Of natural uranium, only 0.7% is uranium 235. This means that a large amount of uranium is needed to obtain the necessary quantities of uranium 235. Additionally, uranium 235 cannot be separated chemically from uranium 238, since the isotopes are chemically similar.

Alternative methods have been developed to separate the isotopes. This is another problem that the Manhattan Project scientists had to face before a bomb could be built.

Research also predicted that Pu 239 would have a high fission probability. However, Pu 239 is not a naturally occurring element; therefore, it would have to be artificially produced. Consequently, the reactors at Hanford, Washington were built to accomplish this.

Spontaneous nuclear fission

The spontaneous nuclear fission rate is the probability per second that a given atom will fission spontaneously (fig. 4–5)—that is, without any external intervention. If a spontaneous fission occurs before the bomb is fully ready, it could fizzle. Pu 239 has a very high spontaneous fission rate compared to the spontaneous fission rate of uranium 235. As a result, scientists had to consider the spontaneous fission rate of each material when designing nuclear weapons.

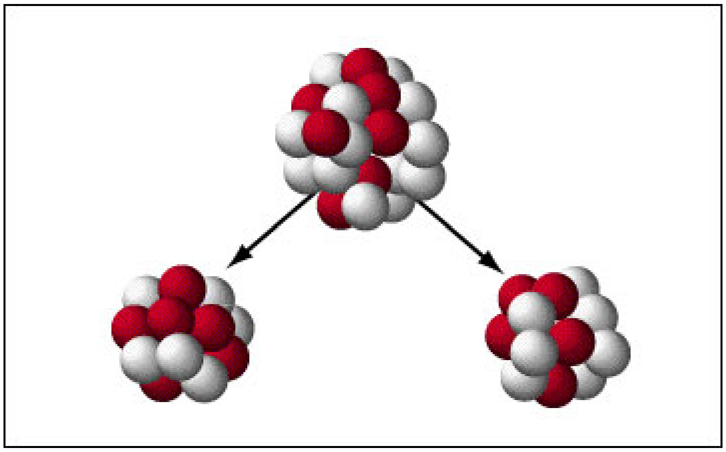

Figure 4–5. Spontaneous Fission.

Nuclear fusion

Nuclear energy can also be released by fusion of two light elements (elements with low atomic numbers like those in figure 4–6). The power that fuels the sun and the stars is nuclear fusion. In a hydrogen bomb, two isotopes of hydrogen, deuterium and tritium are fused to form a nucleus of helium and a neutron. This fusion releases 17.6 MeV of energy. Unlike nuclear fission, there is no limit on the amount of the fusion that can occur.

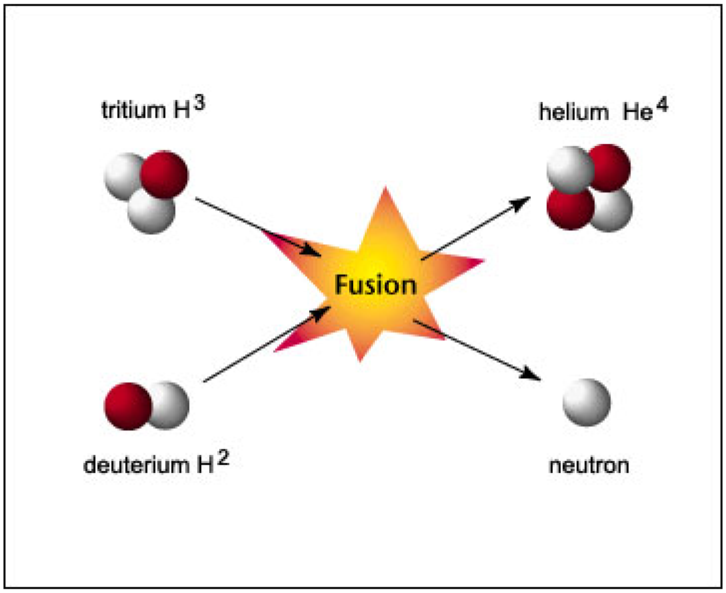

Figure 4–6. Nuclear Fusion.

The energy from a nuclear weapon

Approximately 85% of the energy of a nuclear weapon produces *air blast* (shock) and *thermal energy* (heat). The remaining 15% of the energy is released as various types of nuclear radiation. Of this, five % constitutes the initial nuclear radiation, defined as that produced within a minute or so of the explosion, of mostly gamma rays and neutrons. The final 10% of the total fission energy represents that of the residual (or delayed) nuclear radiation, which is emitted over time. This is largely due to the radioactivity of the fission products present in the weapon residues, or debris, and fallout after the explosion.

The “yield” of a nuclear weapon is a measure of the amount of explosive energy it can produce. The yield is given in terms of the quantity of trinitrotoluene (TNT) that would generate the same amount of energy when it explodes. Thus, a 1 kiloton (1,000 tons) nuclear weapon is one which produces the same amount of energy in an explosion as does 1 kiloton of TNT. Similarly, a 1 megaton weapon would have the energy equivalent of 1 million tons of TNT.

In evaluating the destructive power of a weapons system, it is customary to use the concept of equivalent megatons (EMT). Equivalent megatonnage is defined as the actual megatonnage raised to the two-thirds power:

$$EMT = Y^{2/3} \text{ where Y is in megatons.}$$

This relation arises from the fact that the destructive power of a bomb does not vary linearly with the yield. The volume the weapon’s energy spreads into varies as the cube of the distance, but the destroyed area varies at the square of the distance.

Thus one bomb with a yield of 1 megaton would destroy 80 square miles. While eight bombs, each with a yield of 125 kilotons, would destroy 160 square miles. This relationship is one reason for the development of delivery systems that could carry multiple warheads.

Basic effects of nuclear weapons

Nuclear explosions produce both immediate and delayed destructive effects. The blast, thermal radiation, and prompt ionizing radiation cause significant destruction within seconds or minutes of a nuclear detonation. The delayed effects, such as radioactive fallout (consisting of clouds of fine radioactive dust particles and debris) and other possible environmental effects, inflict damage over an extended period ranging from hours to years. Each of these effects are calculated from the point of detonation.

The effects of nuclear explosions shown in figure 4–7 can be divided into four categories:

1. Blast effect.
2. Thermal effect.
3. Direct radiation effects.
4. Residual radiation (fallout).

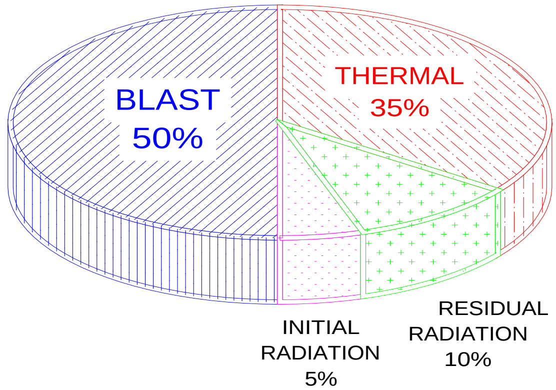

Figure 4–7. Nuclear Explosion Effects.

Blast effects

Initially, most of the thermal radiation goes into heating the bomb materials and the air in the vicinity of the blast. Temperatures of a nuclear explosion reach those in the interior of the sun, about 100,000,000° Celsius, and produce a brilliant fireball.

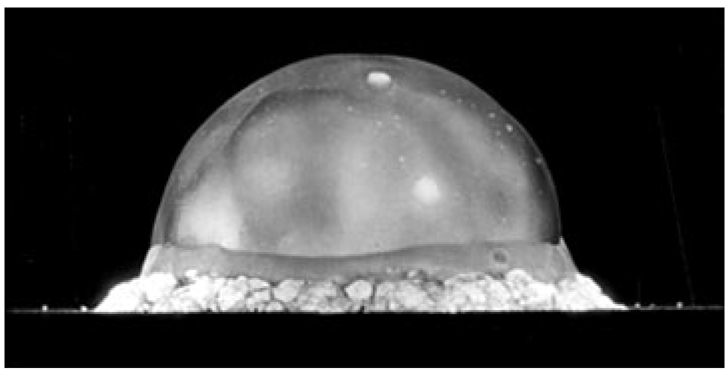

Figure 4–8. The fireball shortly after detonation.

The fireball

The fireball (fig. 4–8 and 4–9), an extremely hot and highly luminous spherical mass of air and gaseous weapon residues, occurs within less than one millionth of one second of the weapon's detonation. Immediately after its formation, the fireball begins to grow, engulfing the surrounding air and pushing out a shockwave. This growth is accompanied by a decrease in temperature because of the accompanying increase in mass. At the same time the fireball rises, like a hot-air balloon. Within seven-tenths of one millisecond from the detonation, the fireball from a 1-megaton weapon is about 440 feet across, and this increases to a maximum value of about 5,700 feet in 10 seconds. It is then rising at a rate of 250 to 350 ft/sec. After a minute, the fireball has cooled to such an extent that it no longer emits visible radiation. It has then risen roughly 4.5 miles from the point of burst.

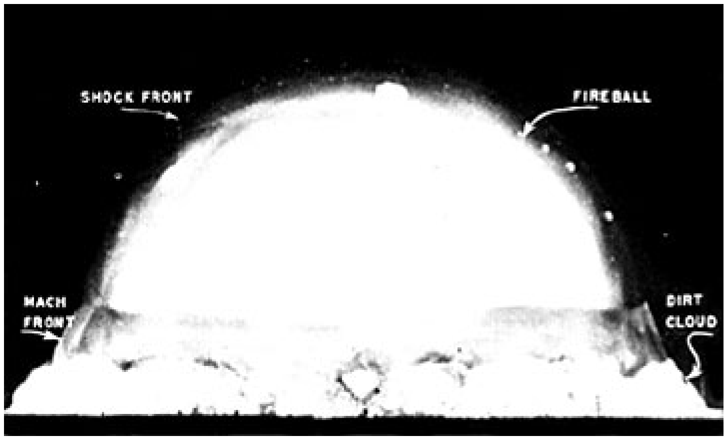

Figure 4–9. Illustrated components of a nuclear explosion.

Most damage comes from the explosive blast wave. The shock wave of air radiates outward, producing sudden changes in air pressure that can crush objects, and high winds that can knock objects down and send debris flying into other objects. In general, large buildings are destroyed by the change in air pressure, while people and objects such as trees and utility poles are destroyed by the wind.

The magnitude of the blast effect is related to the height of the burst above ground level. For any given distance from the center of the explosion, there is an optimum burst height that will produce the greatest change in air pressure, called overpressure, and the greater the distance the greater the optimum burst height. As a result, a burst on the surface produces the greatest overpressure at very close ranges, but less overpressure than an air burst at somewhat longer ranges.

When a nuclear weapon is detonated on or near Earth's surface, the blast digs out a large crater. Some of the material that used in be in the crater is deposited on the rim of the crater; the rest is carried up into the air and returns to Earth as radioactive fallout. An explosion that is farther above the Earth's surface than the radius of the fireball does not dig a crater and produces negligible immediate fallout. For the most part, a nuclear blast kills people by indirect means rather than by direct pressure.

The blast wave

A fraction of a second after a nuclear explosion, the heat from the fireball causes a high-pressure wave to develop and move outward, producing the blast effect. The front of the blast wave, i.e., the shock front, travels rapidly away from the fireball, a moving wall of highly compressed air.

The air immediately behind the shock front is accelerated to high velocities and creates a powerful wind. In turn, these winds create dynamic pressure against the objects facing the blast. Shock waves cause a virtually instantaneous jump in pressure at the shock front. The combination of the pressure jump (called the overpressure) and the dynamic pressure causes blast damage (fig. 4–10). Both the overpressure and the dynamic pressure reach to their maximum values upon the arrival of the shock wave. They then decay over a period ranging from a few tenths of a second to several seconds, depending on the blast's strength and the yield.

Figure 4–10. The effects of the blast wave on a typical wood framed house.

Blast damage is caused by the arrival of the shock wave created by the nuclear explosion. Humans are quite resistant to the direct effect of overpressure. Pressures of over 40 psi are required before lethal effects are noted.

The danger from overpressure comes from the collapse of buildings that are generally not as resistant (fig. 4–11). Urban areas contain many objects that can become airborne, and the destruction of buildings generates many more. The collapse of the structure above can crush or suffocate those caught inside. Serious injury or death can also occur from impact after being thrown through the air. The blast also magnifies thermal radiation burn injuries by tearing away severely burned skin. This creates raw open wounds that readily become infected.

Figure 4–11. Blast effects on a concrete building at Hiroshima.

Thermal effects

Approximately 35% of the energy from a nuclear explosion is an intense burst of thermal radiation, that is, heat. The effects are similar to the effect of a two-second flash from an enormous sunlamp.

Since the thermal radiation travels at roughly the speed of light, the flash of light and heat precedes the blast wave by several seconds, just as lightning is seen before thunder is heard.

Two pulses of thermal radiation emerge from the fireball. The first pulse, which lasts about a tenth of a second, consists of radiation in the ultraviolet region. The second pulse, which may last for several seconds, carries about 99% of the total thermal radiation energy. It is this radiation that is the main cause of skin burns and eye injuries suffered by exposed individuals and causes combustible materials to break into flames (fig. 4–12).

Figure 4–12. The thermal pulse charring the paint.

Thermal radiation damage depends very strongly on weather conditions. Clouds or smoke in the air can considerably reduce effective damage ranges versus clear air conditions.

The energy from the thermal pulse can initiate fires in dry, flammable materials, such as dry leaves, grass, old newspaper, thin dark flammable fabrics, etc. The incendiary effect of the thermal pulse is also substantially affected by the later arrival of the blast wave, which usually blows out any flames that have already been kindled. However, smoldering material can reignite later.

The major incendiary effect of nuclear explosions is caused by the blast wave. Collapsed structures are much more vulnerable to fire than intact ones. The blast reduces many structures to piles of kindling, the many gaps opened in roofs and walls act as chimneys, gas lines are broken open, and storage tanks for flammable materials are ruptured. The primary ignition sources appear to be flames and pilot lights in heating appliances (furnaces, water heaters, stoves, etc.). Smoldering material from the thermal pulse can be very effective at igniting leaking gas.

Thermal radiation damage depends very strongly on weather conditions. Cloud cover, smoke, or other obscuring material in the air can considerably reduce effective damage ranges versus clear air conditions. Thermal radiation also affects humans both directly—by flash burns on exposed skin—and indirectly—by fires started by the explosion.

Flash burns

Skin burns result from higher intensities of light, and therefore take place closer to the point of explosion. First-degree, second-degree and third-degree burns can occur at distances of five miles away from the blast or more. Third-degree burns over 24% of the body, or second-degree burns over 30% of the body, will result in serious shock, and will probably prove fatal unless prompt, specialized medical care is available. The entire US has facilities to treat 1,000 or 2,000 severe burn cases. A single nuclear weapon could produce more than 10,000.

The thermal radiation from a nuclear explosion can directly ignite kindling materials. In general, ignitable materials outside the house, such as leaves or newspapers, are not surrounded by enough combustible material to generate a self-sustaining fire. Fires more likely to spread are those caused by thermal radiation passing through windows to ignite beds and overstuffed furniture inside houses. Another possible source of fires, which might be more damaging in urban areas, is indirect. Blast damage to stores, water heaters, furnaces, electrical circuits or gas lines would ignite fires where fuel is plentiful.

Flash burns are one of the serious consequences of a nuclear explosion. Flash burns result from the absorption of radiant energy by the skin of exposed individuals. A distinctive feature of flash burns is the fact they are limited to exposed areas of the skin facing the explosion (fig. 4–13).

Figure 4–13. The burns are in a pattern corresponding to the dark portions of the kimono she was wearing at the time of the explosion.

A 1-megaton explosion can cause first-degree burns (a bad sunburn) at a distance of about 7 miles, second-degree burns (producing blisters and permanent scars) at distances of about 6 miles, and third-degree burns (which destroy skin tissue) at distances up to 5 miles. It has been estimated that burns caused some 50% of the deaths at Hiroshima and Nagasaki.

Flash blindness

The visible light will produce "flash blindness" in people who are looking in the direction of the explosion. Flash blindness can last for several minutes, after which recovery is total. If the flash is focused through the lens of the eye, a permanent retinal burn will result. At Hiroshima and Nagasaki, there were many cases of flash blindness, but only one case of retinal burn, among the survivors. On the other hand, anyone flash blinded while driving a car could easily cause permanent injury to himself and to others.

During the daylight hours, flash blindness does not persist for more than 2 minutes, but generally lasts a few seconds. At night, when the pupil is dilated, flash blindness will last for a longer period of time.

A 1-megaton explosion can cause flash blindness at distances as great as 13 miles on a clear day, or 53 miles on a clear night. If the intensity is great enough, a permanent retinal burn will result.

Retinal injury is the most far-reaching injury effect of nuclear explosions, but it is relatively rare since the eye must be looking directly at the detonation. Retinal injury results from burns in the area of the retina where the fireball image is focused.

Radiation effects

The release of radiation is a phenomenon unique to nuclear explosions. There are several kinds of ionizing radiation emitted; emitted not only at the time of detonation (initial radiation) but also for long periods of time afterward (residual radiation).

Direct radiation

Direct radiation occurs at the time of the explosion. It can be very intense, but its range is limited. For large nuclear weapons, the range of intense direct radiation is less than the range of lethal blast and thermal radiation effects. However, in the case of smaller weapons, direct radiation may be the lethal effect with the greatest range. Direct radiation did substantial damage to the residents of Hiroshima and Nagasaki. Human response to ionizing radiation is subject to great scientific uncertainty and intense controversy. It seems likely that even small doses of radiation do some harm.

Initial nuclear radiation is defined as the radiation that arrives during the first minute after an explosion and is mostly gamma and neutron radiation. The level of initial nuclear radiation decreases rapidly with distance from the fireball to where less than one R may be received five miles from ground zero. In addition, initial radiation lasts only as long as nuclear fission occurs in the fireball. Initial nuclear radiation represents about 3% of the total energy in a nuclear explosion.

Though people close to ground zero may receive LDs of radiation, they are concurrently being killed by the blast wave and thermal pulse. In typical nuclear weapons, only a relatively small proportion of deaths and injuries result from initial radiation.

Residual radiation (or fallout)

Predictions of the amount and levels of the radioactive fallout are difficult because of several factors. These include the yield and design of the weapon, the height of the explosion, the nature of the surface at ground zero, and the meteorological conditions, such as wind direction and speed.

While any nuclear explosion in the atmosphere produces some fallout, the fallout is far greater if the burst is on the surface, or at least low enough for the fireball to touch the ground. An air burst can produce minimal fallout if the fireball does not touch the ground. On the other hand, a nuclear explosion occurring at or near the earth’s surface can result in severe contamination by the radioactive fallout.

Fallout is received from particles that are made radioactive by the effects of the explosion, and subsequently distributed at varying distances from the site of the blast. Over 300 different fission products may be produced from a fission reaction, many of which are radioactive with widely differing half-lives. Some are very short, i.e., fractions of a second, while a few are long enough that the materials can be a hazard for months or years.

The significant hazards come from particles scooped up from the ground and irradiated by the nuclear explosion. The radioactive particles that rise only a short distance (those in the “stem” of the familiar mushroom cloud) will fall back to earth within a matter of minutes, landing close to the center of the explosion. Such particles are unlikely to cause many deaths because they will fall in areas where most people have already been killed. However, the radioactivity will complicate rescue efforts or eventual reconstruction.

The radioactive particles that rise higher will be carried some distance by the wind before returning to Earth, and hence the area and intensity of the fallout is strongly influenced by local weather conditions. Much of the material is simply blown downwind in a long plume. Rainfall also can have a significant influence on the ways in which radiation from smaller weapons is deposited, since rain will carry contaminated particles to the ground. The areas receiving such contaminated rainfall would become "hot spots," with greater radiation intensity than their surroundings.

Most of the radiation hazard from nuclear bursts comes from short-lived radionuclides external to the body; these are generally confined to the locality downwind of the weapon burst point. Their principal mode of decay is by the emission of beta particles and gamma radiation. Fallout is defined as one of two types: early fallout, within the first 24 hours after an explosion, or delayed fallout, which occurs days or years later.

Many fallout particles are especially hazardous biologically. Some of the principal radioactive elements are as follows:

- Strontium (Sr) 90 is very long-lived with a half-life of 28 years. It is chemically similar to calcium, causing it to accumulate in growing bones. This radiation can cause tumors, leukemia, and other blood abnormalities.
- Iodine 131 has a half-life of 8.1 days. Ingestion of it concentrates in the thyroid gland. The radiation can destroy all or part of the thyroid. Taking potassium iodide can reduce the effects.
- Tritium released varies by bomb design. It has a half-life of 12.3 years and can be easily ingested, since it can replace a hydrogen in water. The beta radiation can cause lung cancer.
- Cs-137 has a half-life of 30 years. It behaves similar to potassium and will distribute fairly uniformly throughout the body. This can contribute to gonadal irradiation and genetic damage.
- Pu 239 has a half-life of 24,400 years. Ingestion of as little as 1 microgram of plutonium, a barely visible speck, is a serious health hazard causing the formation of bone and lung tumors.

The fallout pattern

The details of the actual fallout pattern depend on wind speed and direction and on the terrain. The fallout will contain about 60% of the total radioactivity. The largest particles will fall within a short distance of ground zero. Smaller particles will require many hours to return to earth and may be carried hundreds of miles. This means that a surface burst can produce serious contamination far from the point of detonation.

From the 15-megaton thermonuclear device tested at Bikini Atoll on March 1, 1954—the BRAVO shot of Operation CASTLE—the fallout caused substantial contamination over an area of more than 7,000 square miles. The contaminated region was roughly cigar-shaped and extended more than 20 miles upwind and over 350 miles downwind.

Fallout can also enter the stratosphere. In this stable region, radioactive particles can remain from 1 to 3 years before returning to the surface.

Electromagnetic pulse

Electromagnetic pulse (EMP) is an electromagnetic wave similar to radio waves, which results from secondary reactions occurring when the nuclear gamma radiation is absorbed in the air or ground. It differs from the usual radio waves in two important ways. First, it creates much higher electric field strengths. Whereas a radio signal might produce a thousandth of a volt or less in a receiving antenna, an EMP pulse might produce thousands of volts. Secondly, it is a single pulse of energy that disappears completely in a small fraction of a second. In this sense, it is rather similar to the electrical signal from lightning, but the rise in voltage is typically a hundred times faster. This means that most equipment designed to protect electrical facilities from lightning works too slowly to be effective against EMP.

There is no evidence that EMP is a physical threat to humans. However, electrical or electronic systems, particularly those connected to long wires such as power lines or antennas, can be damaged. There could be actual physical damage to an electrical component or a temporary disruption of operation.

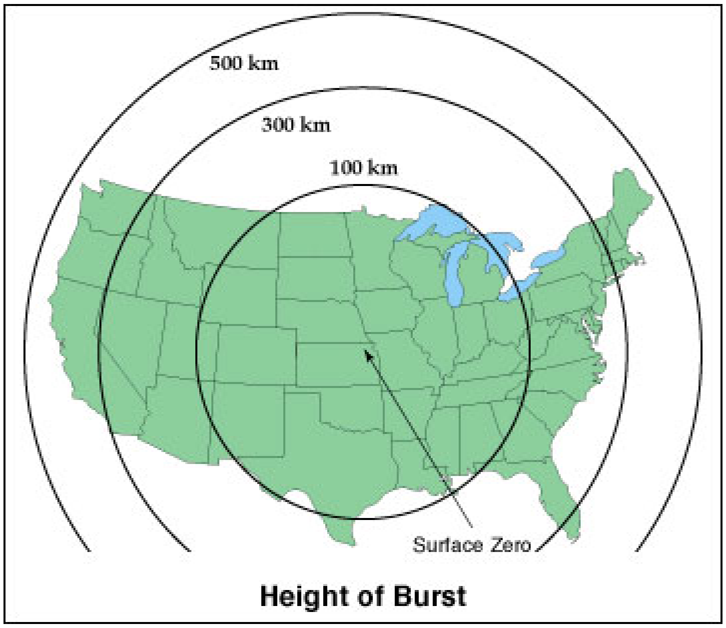

Figure 4–14. The range of the EMP effects of a high altitude burst.

An attacker might detonate a few weapons at high altitudes in an effort to destroy or damage the communications and electric power systems (fig. 4–14). It can be expected that EMP would cause massive disruption for an indeterminable period and would cause huge economic damages. On July 8, 1962, the EMP from the high altitude (250 miles above Johnston Island) "Starfish Prime" test (1.4 megatons) turned off 300 streetlights in Oahu, Hawaii (740 miles away).

Types of nuclear explosions

The effects of a nuclear explosion depend on factors such as weapons design and yield, location, weather, the height of the detonation or burst. There five general classifications of bursts: *high-altitude*, *air*, *surface*, *underwater*, and *underground*.

A detonation above 100,000 feet (30,480 meters) is generally referred to as a high-altitude burst. An air burst is defined as one in which the explosion occurs at an altitude below 100,000 feet, but at such a height that the fireball does not touch the surface of the earth.

A nuclear explosion that occurs at or slightly above the actual surface of the land or H_2O is known as a surface burst. If the explosion happens beneath the surface of the land or H_2O, then it is known as underground or underwater respectively. The design of the Robust Nuclear Earth Penetrator (RNEP) uses the characteristics of an underground burst in an attempt to destroy buried targets.

The greatest difference of each type of burst is the amount of radioactive debris and fallout, and the force of the blast wave.

Ground zero

The term "ground zero" refers to the point on the earth's surface immediately below (or above) the point of detonation. For a burst over (or under) water, the corresponding point is generally called "surface zero." The term "surface zero" or "surface ground zero" is also commonly used for ground surface and underground explosions. In some publications, ground (or surface) zero is called the "hypocenter" of the explosion.

645. Types of nuclear weapons/threats

Planners contemplating the use of any offensive weapons must consider the political and military objectives and the desired degree of destruction, then factor in the local conditions and available weapons and delivery systems. The immediate operational impact of a nuclear detonation varies and may come from blast and heat, the subsequent EMP, or more far-reaching effects, depending on the variables discussed previously. This will have an immediate effect on enemy forces, logistics, and command and control. Communications and computer capability will be severely impacted by EMP, which is an operational effect that may lead to a long-term, strategic impact if the enemy is unable to completely restore those capabilities. Another operational effect with strategic implications is radiation, which will limit the effectiveness of enemy forces as they take protective measures but may also render enemy territory uninhabitable for a long period of time.

Fission based nuclear weapons

The two types of fission based nuclear weapons we will discuss include gun-type and implosion-type nuclear bombs.

Gun-type nuclear bomb

Gun-type nuclear bombs use high explosives (HE) to drive one sub-critical mass of enriched uranium (> 90% ^{235}U) into a stationary sub-critical mass of enriched uranium with enough force to form a critical mass (fig. 4–15). When this is done quickly enough, it generates an uncontrolled chain reaction. The uranium fission bomb detonated over Hiroshima was estimated to kill, injure, or cause the missing of a total of 130,000 people, while leaving an additional 177,000 homeless. This type of device had not been tested prior to its use and has not been used since.

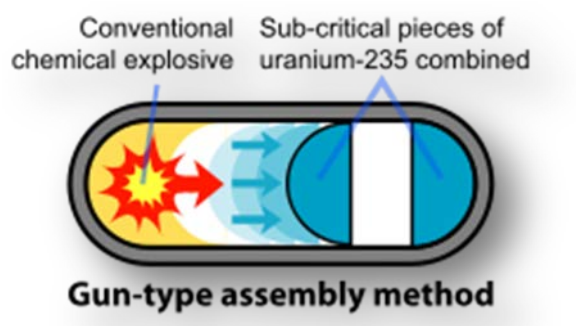

Figure 4–15. Gun-Type nuclear weapon.

Implosion-type nuclear bomb

Plutonium is used in implosion-type nuclear bombs where the plutonium is arranged in a spherical shape (as in a core) with HEs driving the sub-critical ^{239}Pu inward, using ‘lenses’ to focus the explosion (fig. 4–16). The HEs are wired to detonate simultaneously to compress the plutonium with enough force to increase the density to a super-critical arrangement. An implosion device was first tested in Alamogordo, and then one was detonated over Nagasaki. Plutonium does not exist naturally in enough quantity for use in nuclear bombs. In order to create plutonium bombs, *breeder reactors* like Savannah River Plant, SC and Hanford, WA surround a fission reactor with a ^{238}U ‘blanket’ that absorbs the neutrons to produce ^{239}Pu.

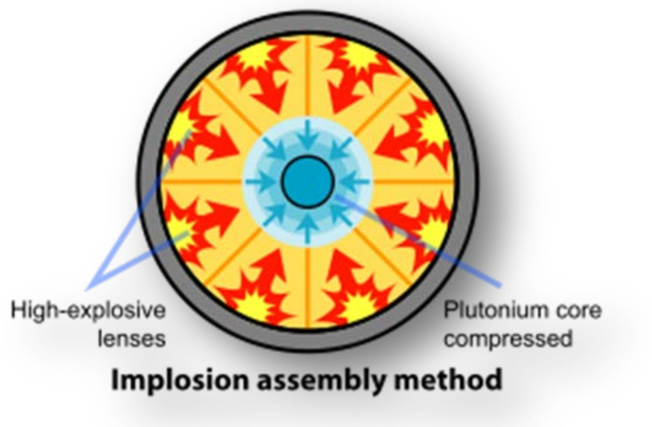

Figure 4–16. Implosion-Type nuclear weapon.

Fusion based nuclear weapons

Let us take a look at two fusion based nuclear weapons, including the hydrogen bomb and the neutron bomb.

The hydrogen bomb

This is a fission bomb, called the primary, which produces a flood of radiation including a large number of neutrons. This radiation impinges on the thermonuclear portion of the bomb, known as the secondary. The secondary consists largely of lithium deuteride. The neutrons react with the lithium, producing tritium and helium (fig. 4–17). In the extreme heat that exists in the bomb, the tritium fuses with the deuterium in the lithium deuteride.

$$Li_3^6 + n \rightarrow He_2^4 + H_1^3$$

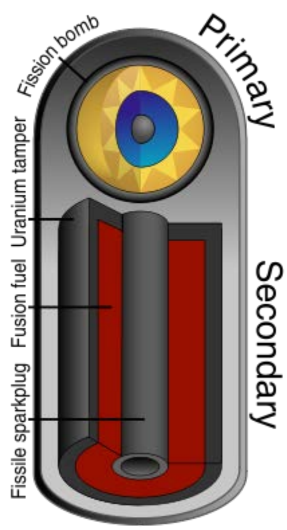

Figure 4–17. Fission-Type nuclear weapon.

The neutron bomb

The neutron bomb is a small hydrogen bomb; it differs from standard nuclear weapons insofar as its primary lethal effects come from the radiation damage caused by the neutrons it emits. It is also known as an enhanced-radiation weapon (ERW).

The augmented radiation effects mean that blast and heat effects are reduced so that critical physical structures are less affected. Because neutron radiation effects drop off very rapidly with distance, there is a sharper distinction between areas of high lethality and areas with minimal radiation doses.

This was desired by the forces of the North Atlantic Treaty Organization (NATO), since they had to be prepared to fight in sensitive areas (any tactical nuclear explosion will endanger civilian lives and property), but minimal development effort has been spent on these types of bombs.

Other nuclear threats

We will continue this discussion with other nuclear threats.

Radiological and nuclear terrorism

> *"Today, the Cold War has disappeared but thousands of those weapons have not. In a strange turn of history, the threat of global nuclear war has gone down, but the risk of a nuclear attack has gone up. More nations have acquired these weapons. Testing has continued. Black market trade in nuclear secrets and nuclear materials abound. The technology to build a bomb has spread. Terrorists are determined to buy, build or steal one." … "We must ensure that terrorists never acquire a nuclear weapon. This is the most immediate and extreme threat to global security."*
>
> *President Barack Obama*
> *Prague, Czech Republic, April, 2009*

Radiological weapons (often referred to as dirty bombs) are thought by many to be the likely choices for terrorists and can kill or injure people by exposing them to RAMs, such as Cs–137, iridium–192 or cobalt–60. Unlike nuclear weapons, they spread RAM, which contaminates equipment, facilities, and land and acts as a toxic chemical, which can be harmful, and in some cases fatal.

Methods of detonating a dirty bomb include devices used to disperse harmful RAM, such as bombs, artillery shells, or other improvised explosives. They can be used to contaminate livestock, fish and food crops. Most RAMs are not soluble in H_2O, which virtually rules it out as a way for terrorists to contaminate reservoirs or other H_2O supplies.

In another possible scenario, terrorists could launch a systemic attack on a nuclear power plant by venting or overloading a reactor, so it acts as a radiological weapon. This type of scenario, referred to as a Faded Giant, is less likely to happen due to several security and safety implementations utilized while constructing nuclear facilities.

Improvised nuclear device

An improvised nuclear device (IND) is an illicit nuclear weapon bought, stolen, or otherwise originating from a country with nuclear weapons, or a weapon fabricated by a terrorist group from illegally obtained fissile nuclear weapons material (plutonium or highly enriched uranium) that produces a nuclear explosion. The nuclear yield achieved by an IND produces extreme heat, powerful shockwaves, and prompt radiation that would be acutely lethal for a significant distance. It also produces radioactive fallout, which may spread and deposit over very large areas. If a nuclear yield is not achieved, the result would likely resemble a radiological dispersal device (RDD) in which fissile weapons material was utilized. If nuclear yield is achieved, the results would resemble a nuclear explosion with the same physical and medical effects as a nuclear weapon explosion.

Radiological dispersal device

This type of bomb is the most accessible nuclear device for terrorists. It is a regular explosive laced with lower-grade RAM (fig. 4–18). An RDD, or dirty bomb, is a conventional explosive or device, such as a dynamite package, coupled with RAM that scatters when the bomb explodes and creates a threat to public health and safety through the malicious spread of RAM. It kills or injures through the initial blast of the conventional explosive and by airborne radiation and contamination, hence the term "dirty." Such bombs can be miniature devices or as big as a truck bomb. It is not much more difficult to make a dirty bomb than it is to make a conventional bomb.

A dirty bomb is not a nuclear bomb or WMD because nuclear weapons involve a complex nuclear reaction and are thousands of times more devastating. The dirty bomb's destructive power depends on the amount, type, and size of conventional explosives and RAM used.

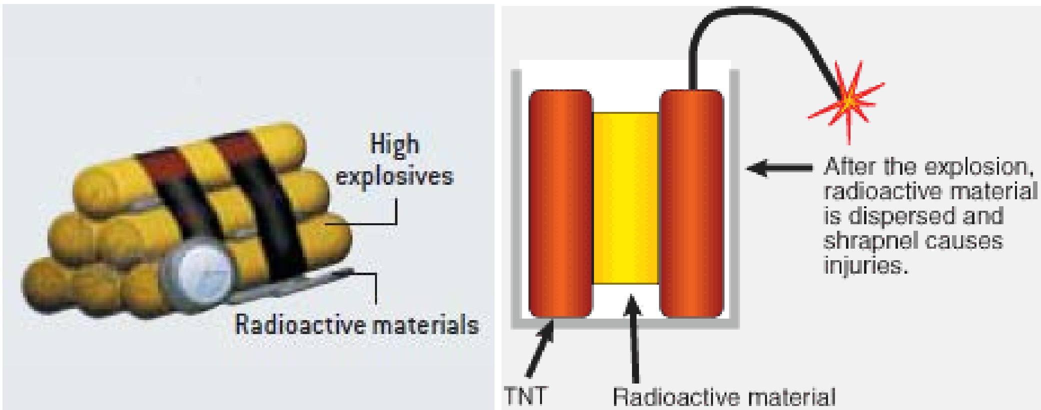

Figure 4–18. Radiological Dispersal Device packaging.

There is a wide range of possible consequences that may result from an RDD, depending on the type and size of the device, and how dispersal is achieved. The consequences of an RDD may range from a small, localized area, such as a single building or city block, to large areas, conceivably several square miles. However, most experts agree that the likelihood of impacting a very large area is low. In most plausible scenarios, the RAM would not result in acutely harmful radiation doses, and the primary public health concern from those materials would be increased risk of cancer to exposed individuals. Hazards may exist as a result of fire, smoke, shock (physical, electrical, or thermal), or shrapnel (from an explosion). Hazardous materials and other chemical or biological agents may also be present.

Radiological exposure device

A radiological exposure device (RED), also referred to as a hidden sealed source, is a terrorist device intended to expose people to significant doses of ionizing radiation without their knowledge (fig. 4–19). Constructed from partially or fully unshielded RAM, an RED could be hidden from sight in a public place (e.g., under a subway seat, in a food court, or in a busy hallway), exposing those who sit or pass close by for several days before being detected. If the seal around the source were broken and the radioactive contents released from the container, the device could become an RDD, capable of causing radiological contamination (https://www.remm.nlm.gov/rdd.htm). The preferred isotopes for an RED consist of medium to high energy gamma (Co–60, Cs–137, Ir–192).

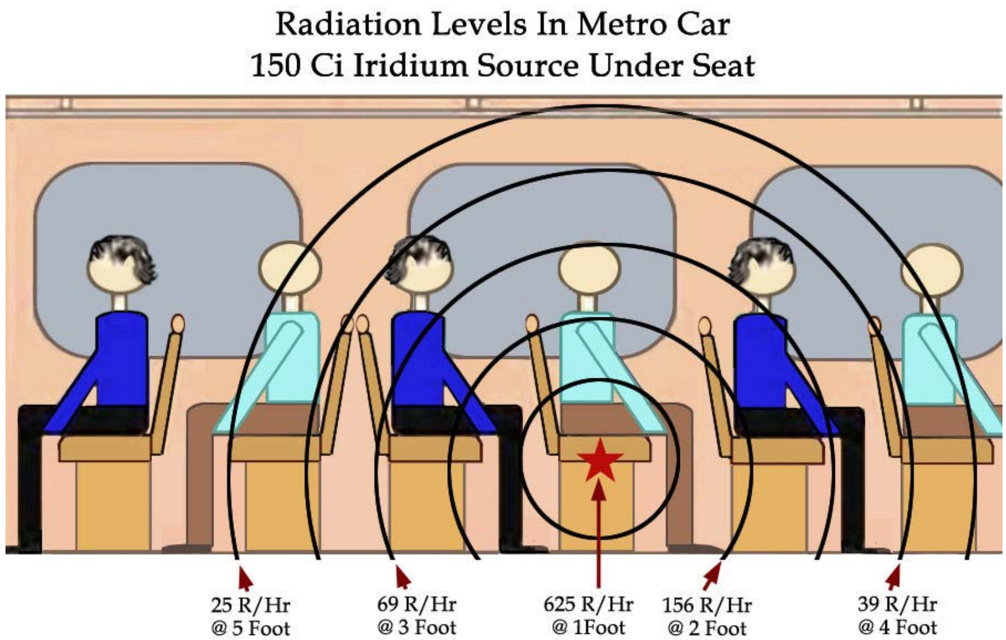

Figure 4–19. Radiological Exposure Device in Metro Car.

Nuclear power

Nuclear facilities may release RAMs to the environment as a result of an attack on the installation or from an accident. A damaged reactor can release large amounts of RAMs, composed of many different radionuclides, over an extended period of time. RAMs of concern include noble gases, halogens (radioiodines), mixed particulate fission products and transuranics (e.g., uranium and plutonium).

An incident at a fuel reprocessing center may involve some noble gases, but mainly mixed particulate fission products and transuranics. Consequently, forces downwind from an incident may face the possibility of both external and internal exposure, over a large affected area and extended period of time.

The hazard posed by internal exposure to radiation is radionuclide specific. Therefore, estimations of effective dose (i.e., the dose from internally deposited nuclides) are highly dependent on identification and quantification of the environmental contamination, particularly airborne contamination.

Electricity can be produced in many ways. In America, nuclear energy plants are the second largest source of electricity after coal—producing approximately 21% of our electricity. While nuclear power plants have many similarities to other types of electricity generating plants, there are some significant differences.

With the exception of solar, wind, and hydroelectric plants, all electricity power plants convert H_2O to steam that spins propeller-like blades of a turbine. This in turn spins the shaft of a generator. In a nuclear power plant, the energy needed to boil H_2O into steam is produced when uranium fuel generates heat through fission. The uranium is formed into ceramic pellets about the size of the end of your finger. These pellets are inserted into long, vertical tubes (fuel rods) within the reactor.

A reactor is the heart of the nuclear power plant and has four main parts. These include uranium fuel assemblies, the control rods, the coolant/moderator, and the pressure vessel. The fuel assemblies, control rods, and coolant/moderator make up what is known as the reactor core. The core is surrounded by the pressure vessel.

The fuel rods, containing the uranium, are carefully bound together into fuel assemblies, each of which contains about 240 rods. The assemblies hold the rods apart so that when they are submerged into the reactor core, H_2O can flow between them.

The control rods slide up and down in between the fuel assemblies in the reactor core. They control or regulate the speed of the nuclear reaction by absorbing neutrons. When the control rods absorb neutrons, fewer neutrons hit the uranium atoms, thus slowing down the chain reaction. On the other hand, when the core temperature goes down, the control rods are slowly lifted out of the core, and fewer neutrons are absorbed. Therefore, more neutrons are available to cause fission. This releases more heat energy.

The NRC regulates commercial nuclear power plants. While there are several types of power reactors, only pressurized water reactors (PWR) and boiling water reactors (BWR) are in commercial operation in the US.

Pressurized water reactors

In a typical commercial PWR (fig. 4–20), the core inside the reactor vessel creates heat. Pressurized H_2O in the primary coolant loop carries the heat to the steam generator. Inside the steam generator, heat from the steam and the steam line directs the steam to the main turbine, causing it to turn the turbine generator. PWRs contain between 150–200 fuel assemblies.

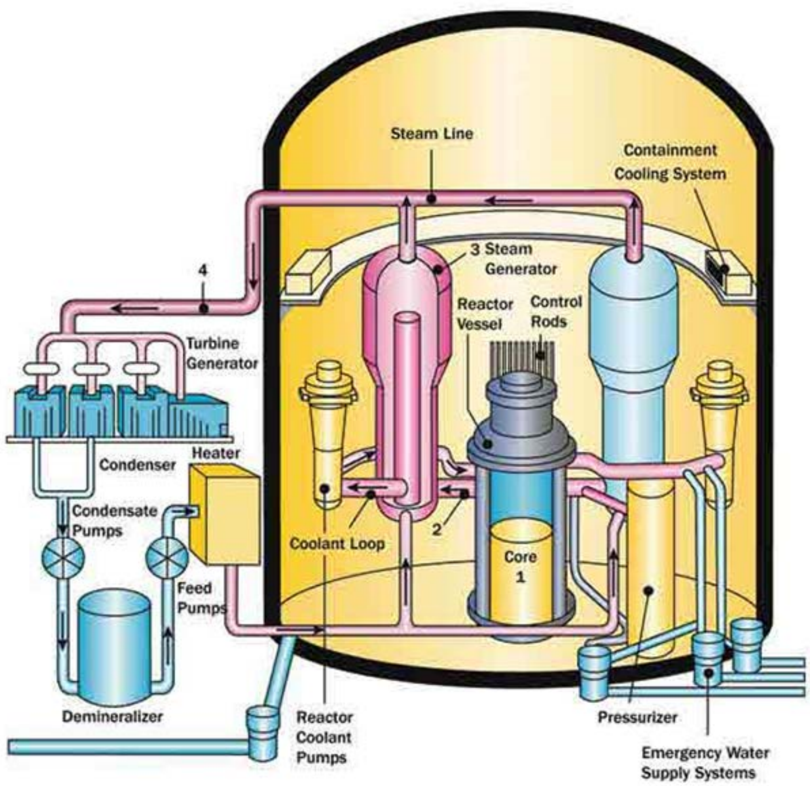

Figure 4–20. Typical Pressurized-Water Reactor.

Boiling water reactors

In a typical commercial BWR (fig. 4–21), the core inside the reactor vessel creates heat. A steam-H_2O mixture is produced when very pure H_2O (reactor coolant) moves upward through the core, absorbing the heat. The steam-H_2O mixture leaves the top of the core and enters the two stages of moisture separation where H_2O droplets are removed before the steam is allowed to enter the steam line, and the steam line directs the steam to the main turbine, causing it to turn the turbine generator. BWRs contain between 370–800 fuel assemblies.

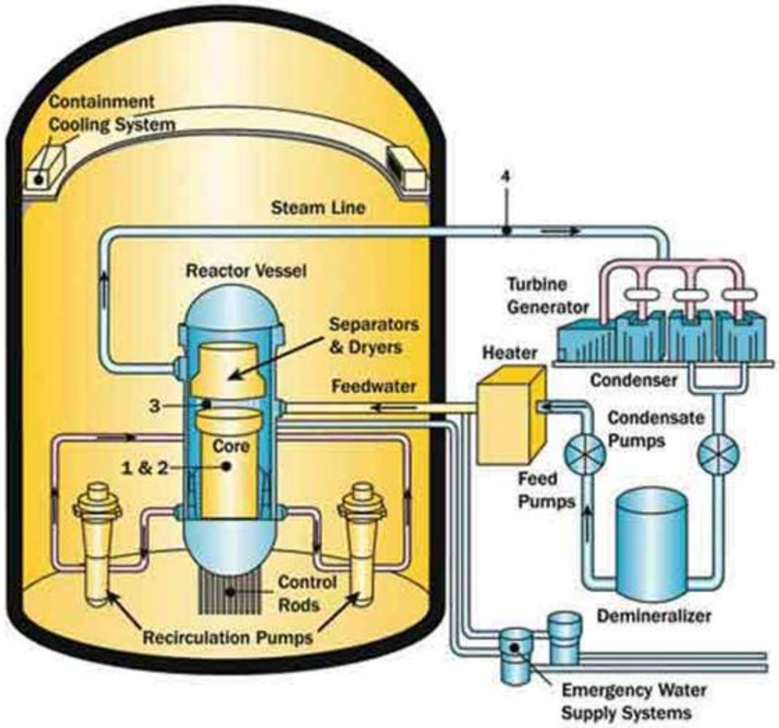

Figure 4–21. Typical Boiling-Water Reactor.

In both systems, the unused steam is exhausted into the condenser where it is condensed into H_2O. The resulting H_2O is pumped out of the condenser with a series of pumps; it is then reheated and pumped back to the reactor vessel. The reactor's core contains fuel assemblies that are cooled by H_2O circulated using electrically powered pumps. These pumps, and other operating systems in the plant, receive their power from the electrical grid. If offsite power is lost, emergency cooling water is supplied by other pumps, which can be powered by onsite diesel generators. Other safety systems, such as the containment cooling system, also need electrical power.

Non-radiological (secondary) hazards to nuclear weapons

During a radiological or nuclear weapons accident/incident, sometimes radiation may not be the only hazard. However, most hazards associated with nuclear weapons are classified. Therefore, in the event of an incident/accident, contact the Air Force Safety Center and the DOE to find which hazards are present on the item(s) involved. Due to the large number of non-radiological (secondary) weapon-specific hazards, it is imperative to recognize those hazards and utilize an "all hazards" approach when responding and performing operations at the site. For example, some of the numerous hazards that may be encountered include HE materials, beryllium, lithium, lead, plastics, hydrazine, red fuming nitric acid, solid fuel rocket motors, jet propulsion (JP) fuel, and composite materials. Each of these hazards are described in the following paragraphs.

High explosive materials

HE materials are energetic, and detonate (instead of deflagrating or burning); the rate that the reaction zone advances into the unreacted material exceeds the velocity of sound in the unreacted material. Many compounds fall into this category, from ammonium nitrate to TNT. Shock, heat, and friction can cause a detonation. For explosives not detonated by heat, fire can change the structure of the material and increase the sensitivity to shock and friction, greatly increasing the chances of detonation.

Many items used in aircraft and other delivery systems contain explosives. These include parachute severance cartridges, ejection seat charges, canopy removers and thrusters, chaff and flare dispensers, and explosive bolts. Other items that may explode when damaged or burned include liquid oxygen bottles, hydraulic accumulators, and tires.

Most information related to HEs used in nuclear weapons is considered *Critical Nuclear Weapons Design Information* (CNWDI), containing top secret restricted data or secret restricted data. CNWDI is restricted due to its revealing of the theory of operation or design of the components of a thermonuclear or implosion-type fission bomb, warhead, demolition munition, or test device. Specifically excluded is information concerning arming, fusing, and firing systems; limited life components; and totally contained quantities of fissionable, fusionable, and high-explosive materials by type. CNWDI may be released after a DOE/National Nuclear Security Administration classification review.

Beryllium

Beryllium is a light, gray-white nonradioactive metal that is hard, brittle, and resembles magnesium. In its solid state (normal state), beryllium is not a personnel hazard. However, in powder, oxide, or gaseous form, it is extremely dangerous. Inhalation is the most significant means of entry into the body. Because it oxidizes easily, any fire or explosion involving beryllium liberates toxic fumes and smoke. One of the peculiarities of beryllium poisoning is that no immediate specific symptoms are apparent.

Pulmonary edema, berylliosis, and breathing related issues

The most common symptom is an acute or delayed type of pulmonary edema (an abnormal buildup of fluid in the air sacs of the lungs, which leads to shortness of breath) or berylliosis (severe inflammation of the lungs). A chronic cough may also result.

Skin contamination and other symptoms

Other commonly occurring signs and symptoms are ulceration and irritation of the skin. Ulceration often occurs when beryllium enters the body through cuts, scratches, or abrasions on the skin. Beryllium also interferes with wound healing; a wound contaminated with traces of beryllium does not heal until the metal is removed. Additional hazards of beryllium include cyanosis (blue or purple coloration due to the tissues near the skin surface having low oxygen), loss of weight, and extreme nervousness.

Protective measures with beryllium

Beryllium or its compounds, when in finely divided form, should never be handled with the bare hands but always with rubber gloves. An M40-series, or equivalent protective mask and/or respirator, and personal protective clothing must be worn in an area known, or suspected, to be contaminated with beryllium dust.

A self-contained breathing apparatus (SCBA) is necessary when beryllium fumes or smoke are present. Decontamination of personnel, terrain, or facilities shall be similar to radiological decontamination. When applicable, an effective method is vacuum cleaning, using a cleaner with a high-efficiency particulate air, absorbing, or arrestance (HEPA) filter. Since beryllium is not radioactive, its detection requires chemical analysis in a properly equipped laboratory. There is currently no technology for direct detection in the field.

Lithium

Lithium and its compounds, usually lithium hydride, may be present at a nuclear weapon accident. Due to its highly reactive nature, naturally occurring lithium is always found chemically with other elements. When exposed to H_2O, a violent chemical reaction occurs, producing heat, hydrogen, oxygen, and lithium hydroxide. The resulting heat causes the hydrogen to burn explosively, producing a great deal of damage.

Lithium may react directly with the H_2O in the body tissue, causing severe chemical burns. Further, lithium hydroxide is a caustic agent that can cause a burning sensation, cough, or difficulty breathing; redness, pain, and blisters to the skin and eyes; and abdominal pain and nausea. Respiratory protection and firefighter clothing are required to protect personnel exposed to fires involving lithium or lithium hydrides. An SCBA is necessary if fumes from burning lithium components are present. The eyes and skin must be protected for operations involving these materials.

Lead

Pure lead and most of its compounds are toxic. The most common routes of entry for lead are inhalation or ingestion. Inhaling lead compounds presents a profoundly serious hazard. Once inside the body, lead concentrates in the kidneys and bones. From the bone deposits, lead is slowly liberated into the bloodstream, causing anemia and resulting in a chronic toxic condition. Lead poisoning displays several specific characteristics and symptoms. The skin of an exposed individual turns yellowish and dry. Digestion is impaired with severe colicky pains, and constipation results. With a high body burden, the exposed individual has a sweet, metallic taste in the mouth and a dark blue coloring of the gums from a deposit of black lead sulfide. Lead concentrations within the body have been reduced successfully by using chelating agents. A respirator with high efficiency particulate filters will protect personnel from inhalation of lead compounds.

Plastics

When involved in a fire, all plastics present varying degrees of toxic hazards due to the gases, fumes, and/or particulates produced. The gaseous or particulate products may initially produce dizziness and physical or mental exhaustion. When placed in contact with skin, it may cause mild and severe dermatitis. If absorbed through the skin, it may result in severe illness, or death if inhaled or ingested. Any fire involving plastics that are not known to be harmless should be approached on the assumption that toxic fumes and particles are present. This includes all nuclear weapon fires.

Hydrazine

Hydrazine is used as a missile fuel or as a fuel in some aircraft emergency power units. Hydrazine is a colorless, oily fuming liquid with a slight ammonia odor. It is a powerful explosive that, when heated to decomposition, emits highly toxic nitrogen compounds and may explode by heat or chemical reaction. Hydrazine is self-igniting when absorbed on earth, wood, or cloth; the fuel burns if ignited with a spark; any contact with an oxidized substance such as rust may also cause combustion. When hydrazine is mixed with equal parts of H_2O, it does not burn; however, it is toxic when inhaled, absorbed through the skin, or taken internally. Causing skin sensitization as well as systemic poisoning, hydrazine may damage the liver or destroy red blood cells. After exposure to hydrazine vapors or liquids, remove clothing immediately and spray exposed area with H_2O for 15 minutes. An SCBA is required in vapor and/or liquid concentrations.

Red fuming nitric acid

Red nitric acid is an oxidizer for some missile propellant systems. It is a reddish brown, highly toxic corrosive liquid with a sharp, irritating, pungent odor. Dangerous when heated to decomposition, it emits highly toxic fumes of nitrogen oxides and reacts with H_2O or steam to produce heat and toxic corrosive and flammable vapors. The permissible exposure level is two parts per million, although a lower concentration causes nasal irritation and severe irritation to the skin, eyes, and mucous membranes. Immediately after exposure, wash acid from skin with copious amounts of H_2O. An SCBA is required in vapor and/or liquid concentrations.

Solid fuel rocket motors

Rocket motors (composed of dymeryl dissocyanate, cured hydroxyl terminated polybutadiene polymer, ammonium perchlorate, and aluminum powder or other cyanate, butadiene, perchlorate, or nitrate-based compounds) present severe explosive hazards if accidentally ignited.

Jet propulsion–10 missile fuel

Jet propulsion (JP)-10 is used as a missile fuel. It is a clear liquid with a kerosene-like odor. Wear an SCBA when firefighting in confined spaces. It is slightly toxic by inhalation; do not allow liquid or mist to enter lungs. Ingestion can be a hazard through JP–10 combining with mucus. Vapor contact causes little to no eye irritation. High heat, sparks, open flame, and strong oxidizers may ignite JP–10 fuel.

Tetrahydromethylcyclopentadiene dimer

Similar to JP–10, tetrahydromethylcyclopentadiene (TH) dimer is also a missile fuel with the same color and odor characteristics. The hazards and firefighting precautions are also similar. TH dimer may cause gastrointestinal irritation (vomiting and diarrhea) and nausea. For prolonged and/or repeated skin contact, appropriate impervious clothing is required (gloves, boots, pants, coat, face protection, etc.).

Composite materials

Composite materials are solids that are composed of two or more substances having different physical characteristics. Such materials might be at the site of a nuclear weapon accident and pose additional health and safety hazards if involved in a fire or explosion. Composite materials are broken down into three categories:

1. Composite—A physical combination of two or more materials (i.e., fiberglass, glass fiber, and epoxy).
2. Advance composite—A material composed of high strength and/or high stiffness fibers (reinforcement) with a resin (matrix). Examples include Graphite/Epoxy, Kevlar®/Epoxy, and Spectra/Cyanate Ester.
3. Advance aerospace material—A highly specialized material used to fulfill unique aerospace construction, environment, and/or performance requirements. Examples include beryllium, DU, and radar absorbent materials.

Carbon, boron, and graphite fibers are milled into composite epoxy packages, which are integral aircraft structural members containing composite fibers (CF). If the epoxy outer layer breaks or catches fire, CF strands may be emitted into the environment and become a respiratory tract, eye, and skin irritation hazard. In the immediate accident area or location where a composite package has broken open, the fibers may cause severe arcing and shorting of electrical equipment.

646. Nuclear weapons incidents/accidents

The destruction wrought by nuclear weapons can be immense, or it can be tailored and limited for a particular scenario, to create fear and chaos, and or support terrorist political and religious agendas. The physical impact of a nuclear strike includes both short- and long-term effects. Beyond the physical repercussions are also significant psychological and political effects, which may lead to intended or unintended consequences.

Since 1950, there have been 32 Nuclear Weapon Accidents. To date, six nuclear weapons have been lost and never recovered. There has never been even a partial or inadvertent US nuclear detonation despite the very severe stresses imposed upon the weapons involved in these accidents. All "detonations" that have been reported involved conventional HEs only. Only two accidents, those at Palomares, Spain and Thule, Greenland, resulted in widespread dispersal of nuclear materials. With each individual nuclear accident or incident, there are a number of code word terms associated with them to describe the level of damage or significance of the event. BEs have to be able to recognize these words and be able to differentiate between an accidents and incident.

The DOD utilizes the following code word terms to identify and report Nuclear Weapons accidents or incidents, as identified in Department of Defense Manual (DODM), 3150.08, *Nuclear Weapon Accident Response Procedures (NARP)*.

Nuclear weapon incident (flagword Bent Spear)

The term or flagword Bent Spear refers to a nuclear weapon incident that is an unexpected event involving a nuclear weapon, nuclear components, or a nuclear weapons transport or launch vehicle when a nuclear weapon is mated, loaded, or on board that does not fall into nuclear weapons accident category. However, it involves damage to the weapon, safety and security, facility, or component resulting in any of the following, but not constituting a nuclear weapon(s) accident:

- An increase in the possibility, or actual occurrence of, an explosion, a nuclear detonation, or radioactive contamination.
- Errors committed in the assembling, testing, loading, or transportation of equipment and materiel which might lead to an unintentional operation of all or part of the weapon arming or firing sequence or which could lead to a substantial change in yield or increased dud probability.
- Loss or destruction of a nuclear weapon or radiological nuclear weapon component due to terrorist or enemy action (see Nuclear weapon theft [flagword Empty Quiver]).
- Non-nuclear detonation or burning of a nuclear weapon or radiological nuclear weapon component.
- Loss or destruction of a nuclear weapon or radiological nuclear weapon component, including jettisoning.
- Public hazard, actual or implied.

Nuclear weapon accident (flagword Broken Arrow)

The term or flagword Broken Arrow refers to an unexpected event involving nuclear weapons or radiological nuclear weapon components that results in any of the following:

- Accidental or unauthorized launching, firing, or use by US forces or US supported allied forces of a nuclear-capable weapon system which could create the risk of an outbreak of war.
- Loss or destruction of a nuclear weapon or radiological nuclear weapon component, including jettisoning.
- An increase in the possibility or actual occurrence of, an explosion, a nuclear detonation, or radioactive contamination.
- Non-nuclear detonation or burning of a nuclear weapon or radiological nuclear weapon component.
- Public hazard, actual or implied.
- Any act of God, unfavorable environment, or condition resulting in damage to the weapon, facility, or component.

Nuclear weapon theft (flagword Empty Quiver)

The term or flagword Empty Quiver refers to the seizure, theft, or loss of a nuclear weapon, to include the following:

- The loss (explained or unexplained) of a nuclear weapon or nuclear component.
- The forcible, unauthorized seizure or theft of a nuclear weapon or nuclear component.

Nuclear weapon safety deficiency (flagword Dull Sword)

The term or flagword Dull Sword is used by any unit to report a nuclear weapon safety deficiency, according to service guidelines. This includes mishaps not falling into the accident or incident categories. The wing safety office is responsible for making all Dull Sword reports IAW AFMAN 91–221, *Weapons Safety Investigations and Reports.*

Nuclear reactor or radiological accident report (flagword Faded Giant

The term or flagword Faded Giant is used to report nuclear reactor or radiological accidents or incidents to the appropriate service headquarters.

Naturally occurring radioactive materials

This refers to RAMs that are found in nature. Naturally occurring RAMs (NORM) or elements include primordial radionuclides that have been present in the rocks and minerals of the earth's crust since it was formed. Cosmogenic radionuclides, produced by interactions of atoms in the atmosphere with cosmic rays, are a second source of NORM. Examples of naturally occurring radionuclides are uranium, radon gas, and carbon, IAW Air Force Policy Directive (AFPD) 13–5, *Air Force Nuclear Mission*.

Technologically enhanced naturally occurring radioactive materials

Until recently, technologically enhanced naturally occurring radioactive materials (TENORM) was referred to simply as NORM. The words "technologically enhanced" were added to distinguish clearly between radionuclides as they occur naturally and radionuclides that human activity has concentrated or exposed to the environment, IAW AFMAN 91-221. TENORM is produced during activities such as uranium mining, or sewage sludge treatment, actually concentrates or exposes RAMs that occur naturally in ores, soils, H_2O, or other natural materials, IAW DODM 3150.08.

Naturally occurring radioactive materials or accelerator-produced radioactive materials

RAMs not covered under the Atomic Energy Act (AEA) are naturally occurring or produced by an accelerator. Accelerators are used in sub-atomic particle physics research. These materials have been traditionally regulated by States. Interestingly, NORM is a subset of naturally occurring radioactive materials or accelerator-produced radioactive materials (NARM), and NARM waste with more than 2 nCi/g of ^{226}Ra or equivalent is commonly referred to as discrete NARM waste. Below this threshold, the waste is referred to as diffuse NARM waste. NARM waste is not covered under the AEA, not a form of low-level radioactive waste, and is not regulated by the NRC.

647. Role of BE in the nuclear enterprise

Military and civilian communities must be protected from the potential health hazards engendered by fabrication, storage, transportation, or physical possession of nuclear devices. Nuclear devices are designed to be inherently safe, but accidents have occurred and can again.

Historically, the general public's reaction to any accident involving a nuclear device has been one of panic. Generally, representatives from businesses or other organizations at or near an accident scene, particularly responding media, will take any action necessary to exploit information regarding the hazards. At the outset, it is imperative that BE personnel not get involved in the dissemination of information to the public; leave this to qualified public affairs (PA) personnel.

In the event of a military response to a radiological accident, incident, or dirty bomb scenario, BE will be the primary radiological health and safety advisor to a military on-scene commander (OSC). To accomplish this role, BE has radiation detection equipment, air sampling equipment, and computer modeling capabilities to measure and project airborne and ground deposition patterns of contamination. With this information, BE aids OSCs in setting up controlled areas, and provides recommendations for respiratory protection and protective clothing, and surveillance activities for personnel in contamination control. Within this role, identification of unknown radiological contaminants is a function that BE performs, with γ-spectroscopy equipment. While identification of unknown radiological contaminants is an important BE function, BE must keep in mind that many of the protective actions it recommends in the initial stages of an accident response may be made without identification of the contaminant. For example, in the initial stages of an accident, BE will conduct air sampling and perform ground monitoring to determine if there is airborne or ground-deposited radiological contamination, whether or not the contamination emits α-, β-, and/or photon radiations, intensity of the contamination, and external exposure rates.

BE must assist the medical facility to be prepared to provide complete medical support at the scene (on or off base), and at the medical facility. This support includes the health care and protection (including environmental/radiological health) of all response personnel at the accident site, any non-military personnel who may have been involved, and control of the health hazards involved in handling radiologically contaminated patients.

The BE capabilities and responsibilities

Radiological monitoring at a nuclear device incident/accident site can be viewed as occurring in three phases. The first phase is beta-gamma monitoring to determine if a nuclear yield has occurred, even though it is only a remote possibility. The second phase is to rapidly define the contaminated areas so they can be controlled. The last phase is continued monitoring of areas, personnel and equipment throughout decontamination and site restoration.

Demands for BE capabilities depend on the magnitude of the incident, type of scenario, availability of installation readiness and emergency management (EM) assets, and the overall missions and capabilities of the medical unit/installation. A CBRN incident will result in a surge in the requirement for BEE support at the scene of the event, supporting medical units, and other point of care locations. The BEE team may be required to perform sample collection and preservation at the scene. BEE personnel must conduct sampling in a manner that preserves crime scene evidence and must maintain positive control of samples. Personnel must document chain-of-custody from the time of collection to delivery for lab analysis.

The BE capabilities and responsibilities in the following paragraphs are outlined in the Air Force Tactics, Techniques, Procedures (AFTTP) 3-42.32, *Home Station Medical Response to Chemical, Biological, Radiological, and Nuclear (CBRN) Incidents*.

Surgeon General-related vulnerability assessments

The BE team is responsible for conducting SG-related vulnerability assessments to identify critical infrastructure and operational components of the installation/location. The team assesses the overall vulnerability of critical nodes, considering threats, probability of occurrence, and consequence of effects and provides recommendations to reduce overall vulnerability and risk to the mission.

Predictive exposure assessments

The team conducts predictive exposure assessments using occupational and environmental health (OEH) data, intelligence products, and modeling information collected in garrison as a baseline for predicting potential OEH exposures across the range of military operations.

Occupational and environmental health threat response

The team is responsible for effective and efficient response to deliberate and crisis incidents that may result in actual or potential exposure to occupational and environmental health (OEH) threats. The team documents information on actual and potential exposures from OEH incidents in the Defense Occupational and Environmental Health Readiness System (DOEHRS) as part of the longitudinal exposure record (LER).

OEH hazard identification

The team is responsible for effectively and efficiently anticipating, recognizing, and analyzing actual and potential CBRN and physical health threats. The team associate's agent effects with the health risk to potentially exposed personnel, working with EM, EOD, and other installation personnel to identify OEH hazards associated with different CBRN effects. The team works through the Threat Working Group to identify probable risks and assist with planning phases for posturing efforts, incorporating potential health risks from the residual effects of weapons (OEH hazards versus direct blast effects) and other contingencies such as toxic industrial chemical (TIC) On 8 July 1962, the EMP from the high altitude (250 miles above Johnston Island) “Starfish Prime” test /toxic industrial material (TIM) releases. The team is responsible for collecting, preserving, packaging, shipping, transporting, and escorting samples associated with CBRN responses at garrison locations, except for biological samples that are shipped or transported by the laboratory biological detection team (LBDT) and escorted by local OSI or Federal Bureau of Investigation (FBI) personnel.

Exposure investigations

The BEE team works with aerospace medicine to evaluate post-exposure outcomes through interviews, re-creations, modeling, post-exposure medical exams, controls implemented, and resulting health effects to document human health threats. The team uses these results to provide recommendations to commanders on ways to reduce risks in future operations and other similar and concurrent operations. The team will document known operational impacts (maximizing positive impacts and minimizing negative impacts).

OEH hazard management

The BEE team is responsible for providing recommendations to eliminate or mitigate actual or potential CBRN and physical OEH threats. They recommend protective postures in counter-chemical, biological, radiological, and nuclear (C-CBRN) operations and assist with shelter management.

Exposure tracking

The team documents information regarding identification, evaluation, and control of actual and potential OEH hazards as part of the LER. They tie completed or potentially completed exposure pathways to individuals using spatial and temporal reference marks.

Health risk management

As part of the health component of the risk management (RM) process, the BEE team communicates OEH risk-based information and advises decision makers on COA to minimize OEH risks and maximize benefits for operations and missions. Health RM recommendations and decisions are integrated into the commander’s RM decision-making. The team is responsible for effectively communicating potential health effects, outcomes, and control measures and providing information consistent with the HRA. The team applies OEH exposure data to groups of similarly exposed individuals.

BE accomplishes these capabilities by performing tasks outlined in Broken Arrow guides often available within a BE on each installation. These tasks often include the following:

- Coordinate with EOD and the emergency operations center (EOC) on hazards identified, device(s) status and site condition, and make recommendations to the OSC.
- Brief all personnel entering area of possible health hazards (radiation and toxic material) that may be encountered and ensure their personal protection (protective clothing and proper respiratory protection). Considerations must be given to the effects of heat and cold stress.
- Ensure that all personnel entering area are issued dosimetry for medical documentation of beta/gamma exposure.
- Initiate air sampling at entry control point(s), around the cordon, and downwind of accident scene.
- Continue air sampling throughout the operation to determine resuspension of alpha radiation; specifically, during recovery operations where any radioactive contaminant could be released to the atmosphere.
- Collect environmental samples; soil, H_2O (upstream and downstream) and vegetation outside the cordon to document background radiation levels. Collect same type samples from inside

cordon and around accident site.

- Ensure time-line recording of all operations for medical documentation. This includes, but is not necessarily limited to, assigning sample collection codes, plotting on a grid map area sample locations (air, H_2O, vegetation), sample times, device location and condition, casualties, etc. A historical log-of-events for medical purposes should be constructed from the documentation of the BE personnel, the medical representative on-scene, and the medical command post (CP).
- Arrange for liaison and interface with other federal, civil, medical and public health agencies as necessary. Brief the on-scene commander (OSC) on DOD and DOE response teams that are available and their capabilities; e.g., Sandia National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Air Force Radiation Assessment Team (AFRAT) and Air Transportable Radioactivity Detection Identification and Computation (RADIAC) Package (ATRAP). Determine if they have been requested.
- Advise medical facility and on-site decontamination station of proper containment and disposal of radioactive waste, to include the containment of wash water.
- Maintain constant surveillance of all monitoring and decontamination procedures at the decontamination station. Further, always ensure that contamination is contained and personnel exposure is minimal.
- In conjunction with Fire Department and EM personnel, determine if a partial nuclear yield has taken place and advise accordingly on health hazards and protective measures.
-

As a minimum, the BE initial reconnaissance team briefing should cover:

- If EOD representative briefed on possible radiation and explosive hazards?
- Are protective clothing and respiratory devices adequate?
- Do team members know how to monitor? Personal dosimeter use? Use in contaminated area?
- Are team radio communications available? Has communications security been addressed?
- Monitoring techniques (Radials/Grids)? What are the exposure limits and what does team do when they are reached? What is the plan to dispose fragments?
- How is(are) exposure(s) recorded?
- Other industrial hygiene considerations? Toxic metal/chemical hazards? Pollutant runoff?
- What are the decontamination procedures?
- How to address personal injury while inside cordon?

A radiological incident may also include chemical contaminants, which may require concurrent implementation of Title 40 CFR Part 300, *National Oil and Hazardous Substances Pollution Contingency Plan*, also known and referred to as the National Contingency Plan which falls under the purview of the EPA.

The apparent US nuclear weapon accident could be terrorist-initiated or otherwise intentional in origin and, therefore, must be investigated as a hostile act. The site is considered a crime scene, until determined otherwise through FBI investigation.

Protection of personnel

Initial response activities begin when the accident occurs, including classification of the event. This phase chiefly comprises actions by first responders—fire, emergency medical, and law enforcement and security personnel—whose response actions focus on extinguishing fires, rescuing victims, treating casualties, and securing the nuclear weapon. The first responders may be civilian, military, or a combination of both. The response team radiation safety is composed of three components—

exposure reduction, dose monitoring, and contamination control.

Perhaps the most effective life-saving opportunity for response officials in the first hour following a nuclear incident/accident will be the decision to shelter populations in the expected dangerous fallout areas. When individuals remain in nuclear fallout areas unsheltered, the fallout deposited on the ground and roofs will lead to an immediate external radiation exposure from beta/gamma radiation.

During a radiological incident, the victims and the responders will be exposed through four pathways described in the following table.

Radiological Incident Exposed Through Four Pathways	
Cloud shine	This is external gamma radiation from a plume of RAM. This component is significant during the initial passage of a plume with beta/gamma emitters because of the high airborne concentration of radionuclides. After the initial plume passes, the amount of airborne contamination is limited to resuspended radioactive particles. In general, the cloud shine from pure alpha emitters is minimal. However, the cloud shine from beta emitters can be significant.
Ground shine	This is external beta/gamma radiation from RAM deposited on the ground. Ground shine increases as the particles in the plume settle and the plume passes. After the passage of the initial plume, the ground shine for beta and beta/gamma emitters is the most significant exposure pathway.
Internal radiation exposure	Inhaling RAM is the primary pathway for internal exposure. This is a significant exposure mode for all RAMs during the passage of the initial plume. Once the plume has passed, inhalation is the major exposure pathway for only alpha emitters. External exposure is most significant for beta/gamma and beta emitters.
Skin contamination exposure	External beta and gamma radiation from RAM deposited on the skin is a significant source of external skin exposure. PPE will completely shield alpha particles and will provide significant shielding for beta particles.

The primary purpose of PPE in a radiological incident is to prevent the internalization of RAM through either inhalation or subsequent hand-to-mouth transfer. Its secondary purpose is to reduce skin exposure by RAMs that emit beta radiation. The proper donning and doffing of PPE will also reduce the spread of RAM from the incident site to other locations.

The most probable means of contamination entering the body is through inhalation. Satisfactory respiratory protection can be provided in most instances by using service approved protective masks. Extremely high contamination levels, suspected presence of tritium, firefighting, and other special situations may require the use of a positive pressure SCBA.

In an emergency situation, since air concentrations may vary considerably, suitable respiratory protection should be worn when entering an area where a release of RAMs is suspected. The use of respiratory equipment should be continued until it is fully established that further work will not generate airborne contamination. From a RM perspective, the most effective dose reduction tool is reducing the time in the field. If wearing PPE significantly increases the time in the field, consideration should be given to not wearing PPE.

PAGs are developed to identify protective devices to limit exposure to the lungs from inhaling contaminants to agreed-on limits. The appropriate derived air concentration (DAC) should be that in Federal Guidance Report (FGR)-11, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*. For plutonium in non-chemically active forms that should be expected after a fire, the DAC is 0.222 becquerel per centimeters cubed (Bq/cm^3) or 13.32 disintegrations per minute per centimeters cubed (dpm/cm^3), which corresponds with the lower portion of the following table, located online at https://www.acq.osd.mil/ncbdp/nm/narp/docs/pdf. The table is part of a NARP Internet supplement to DODM 3105.08. It gives the recommended respiratory protection levels for emergency workers as a function of airborne contamination. The acronyms NIOSH and MSHA have been added in the table for the purpose of this lesson.

Airborne Alpha Activity dpm/m^3 Above Background	Respiratory Protection
Below 13.32 dpm/m^3	No respiratory protection needed.
13.32 to 665 dpm/m^3	Full-face respiratory protection, M-series Protective Mask or National Institute of Occupational Safety and Health (NIOSH)/Mine Safety and Health Administration (MSHA) approved HEPA respirator.
Above 665 dpm/m^3	Pressure demand SCBA or limited entry restricted to essential personnel wearing full-face respiratory protection. Source of contamination should be fixed as soon as possible.

The airborne alpha guidelines provided in the preceding table are intended for use until health physics personnel at the scene can develop situation-specific instructions. In deriving the respiratory protection guidelines, a protection factor of 50 was assumed for full-face air purifying respirator. Such computations assume possible exposures to radiation workers of 13.32 dpm/m3 of ^{239}Pu, 40-hour week, averaged over the period of a year (2,000 hours), which would result in 5 rem the CEDE.

Personnel entering a contaminated area must be fully dressed in anticontamination clothing. This type of clothing will not reduce exposure to gamma radiation, but it will protect against alpha radiation and help prevent the spread of contamination. Personnel respiratory protective measures are determined from measurements of airborne contamination levels. However, during the early stages of accident response, initial selection of respiratory protection can be made using measurements of surface contamination until airborne measurements become available.

Civilian work clothing or military fatigues can, in an emergency, provide some protection from contamination and could be worn in lieu of special anticontamination clothing. Occasionally, for the sake of public relations or to expedite rescue operations, it may be desirable to wear ordinary work clothing into a contaminated area. Any clothing worn in such an environment must be considered expendable and should be processed in the same manner as anticontamination clothing.

Some important factors which influence the selection of anticontamination clothing include weather conditions expected at the scene, the nature and quantity of the contaminant, and the environment in which the clothing is to be worn. Since these factors vary, equipment that can be adapted to a variety of situations may be more useful than single purpose items. In highly contaminated areas, underclothing (socks, shorts, and undershirts) should be worn, which can then be disposed of or laundered at decontamination facilities.

Heavy-duty, close weave, cotton twill, single piece coveralls that cover everything (except the feet, hands, and head) have been worn satisfactorily in dry, highly contaminated areas. Such coveralls are effective in preventing most of the contamination from penetrating underclothing and skin. A second pair of coveralls can be worn over the first pair to allow removal of highly contaminated clothing before proceeding to a primary decontamination facility. Button seams, pocket slits, and small tears or holes in coveralls should be covered with tape. A one-inch fold-over tab should be made on the exposed end of the tape at each sealed juncture for ease in removing the tape from the anticontamination clothing.

Shoes that are expendable should be worn in highly contaminated areas, as protective coverings and decontamination methods are sometimes ineffective. Shoe covers are available in several materials and sizes. Low snap-on canvas or plastic covers are frequently worn in areas of low-level contamination. Rubber boots or galoshes are usually worn in wet areas. High-top rubber shoe covers which are rugged, waterproof, and tearproof are practical for most work in contaminated areas. These “totes” afford more protection than the low shoe covers since coverall cuffs can be tucked into them, and the juncture taped.

A surgeon’s cap can be worn to minimize contamination of the hair and scalp. Plastic or cloth hoods are worn in grossly contaminated areas, which may include a great deal of airborne contamination. Work gloves of cotton, canvas, leather, or plastic are often used in contaminated areas to perform jobs that entail manual labor. Nitrile gloves are used for jobs that require sensitivity of touch; they are often worn under work gloves in highly contaminated areas to give added protection. Rubber gauntlet gloves are used where corrosive liquids, caustics, or wet contaminants are handled. Outer gloves worn in contaminated areas should overlap the wrist of the coveralls and should be taped at the juncture of the glove and wrist. Inner gloves should have the sleeves of the coveralls overlap them.

Dosimetry

Radiation detection methods that do not require a power source are referred to as “passive” methods or systems. The detection medium is usually a solid and is used almost exclusively to characterize cumulative dose rather than dose rate or particle fluence rate (as is the case for many active detection systems). An important use for such detectors is as personnel dosimeters (i.e., devices used to assess an individual’s cumulative external radiation exposure). Personal dosimeters are needed for emergency personnel if they are required to enter high dose-rate areas.

The personnel most likely to receive the highest exposures are those least likely to have any direct personnel monitoring. These individuals are those that arrive on the scene first (e.g., passersby, homeowners, police, firemen, medics and emergency personnel involved in initial rescue and firefighting efforts). This is especially true if the accident scene is not on a military reservation and the individuals involved in the initial response efforts are not aware of the presence of nuclear material.

Dosimeter badges and/or EPDs should be issued to individuals most likely to be exposed in the accident area. If enough dosimeters are not available, and the situation dictates entry into the accident area, it is not necessary to issue dosimeters to every individual. However, dosimeters should be issued to one individual in each group that will stay together, and all individuals in that group are noted and recorded. Any resultant dosimeter reading will be assigned to all members of that group.

Emergency worker turn-back guidance values are given as an integrated external dose on a self-reading dosimeter. The purpose of turn-back guidance is to provide the emergency worker an exposure level (typically 50% of the allowable for mission) at which the emergency worker should cease activities and return to the perimeter of the controlled area (specifically, the contamination control station). Emergency worker turn-back doses are to serve as guidance and not limits; judgment must be used in their application, but all reasonable efforts should be taken not to exceed these values. Make sure that emergency workers fully understand the tasks and radiation protection procedures to be followed before entry into an impacted area. PPE and other physical barriers to communication may exist after the emergency worker enters the area.

For those individuals who may have been present at the accident scene prior to the arrival of the accident response force carrying radiation measurement and dosimetric devices, careful documentation will be required in order to ensure that a reasonable dose reconstruction can later be accomplished. Immediate efforts must be made to record the name, SSANs, local addresses, and means of contact for all such personnel. Efforts must be made while the circumstances are fresh in their memory to document the exact location(s) and duration(s) of each individual's stay in the accident area.

For routine exposure of occupational workers, the maximum permissible dose is well defined (5 rem/year and no more than 3 rem/quarter). However, a nuclear incident/accident is not a routine occupational environment, therefore, these limits may not apply. Nevertheless, these limits can be used initially until radiation experts at the scene determine whether special limits will be instituted. If individuals have been working in high radiation areas prior to maximum stay times being established, radiation safety experts can retrospectively estimate external doses received by these individuals using any measurements recorded and can then advise as to whether further exposure may be permitted.

Effective dose

In the aftermath of a radiological emergency, the public will see radiation and its potential hazards described in many different and sometimes confusing ways. As radiation moves through the body, it dislodges electrons from atoms, disrupting molecules. Each time this happens, the radiation loses some energy until it escapes from the body or disappears.

The energy the radiation deposits in tissue is called the *dose*, or more correctly, the *D*. The units of measure for D are the Gy (1 joule per kilogram of tissue) or the *rad* (1/100 of a Gy). The *cumulative dose* is the total D or energy deposited by the body or a region of the body from repeated or prolonged exposures. The absorption of radiation in tissue is the most important factor in determining radiation exposure hazard potential. A measure of the biologic risk of the energy deposited is the *effective dose* or *dose equivalent*. The units of dose equivalent are *Sieverts* or *rem*. If a dose in Gy (rad) is multiplied by a quality factor, the result is the effective dose in units of Sieverts (rem). An external whole-body gamma dose of 2 centisieverts (cSv) will produce the same increase in cancer risk as an external whole-body neutron dose of 2 cSv.

External, internal, and absorbed doses

A person can receive an *external dose* by standing near a gamma or high-energy beta-emitting source. A person can receive an *internal dose* by ingesting or inhaling RAM. The external exposure stops when the person is decontaminated and leaves the area of the source. The internal exposure continues until the RAM is flushed from the body by natural processes or decays.

A person who has ingested a RAM receives an internal dose to several different organs. The absorbed dose to each organ is different, and the sensitivity of each organ to radiation is different. FGR–11 assigns a different weighting factor to each organ. To determine a person's risk for cancer, multiply each organ's dose by its weighting factor, and add the results; the sum is the *effective H*.

NOTE: The term "effective" means it is not really the dose to the whole body, but a sum of the relative risks to each organ. The term "equivalent" means it is presented in rem or Sieverts instead of rads or Gy.

Committed and total effective dose equivalents

When a person inhales or ingests a radionuclide, that radionuclide is distributed to different organs and stays there for days, months, or years until it decays or is excreted. The radionuclide will deliver a radiation dose over a period of time. The dose that a person receives from the time the nuclide enters the body until it is gone is the *committed dose*. FGR–11 calculates doses over a 50-year period and presents the *committed dose equivalent* for each organ plus the CEDE. A person can receive both an internal dose and an external dose. The sum of CEDE and the external dose is called the TEDE.

Electronic personal dosimeters

The EPD is an advanced electronic personal dosimeter designed to detect, monitor, and record personnel gamma/X-ray and beta radiation exposure. The EPD can be used for routine operations to monitor real-time ionizing radiation exposures or used in emergency or disaster response situations where the presence of ionizing radiation is unknown.

The EPD can provide a dose-of-record for personnel exposed to ionizing radiation, but only if the device is issued and read by the USAF RDL or the emergency response RadDos team. The EPD does not detect alpha or neutron radiation and will not accurately measure radiation produced from digital pulse X-ray machines. The EPD is not able to accurately measure digital pulse X-ray units where the pulse is shorter than 0.5 microseconds (500 nanoseconds).

Dose alarms are calculated against a preset alarm threshold set in the EPD. When the dose equals or exceeds the dose threshold, the LED will illuminate, the sounder will activate, and the appropriate alarm flag on the LCD will be displayed. Dose rate alarms are checked and updated every second, except at low dose rates where this period increases to a maximum of 14 seconds.

Three dose rate alarm flags indicate that a dose rate has exceeded the dose rate alarm thresholds. Whereas Hp refers to a personal dose equivalent, Hp(10) signifies the equivalent dose is 10 millimeters (mm) below a specified point of the body surface (or a deep dose). Similarly, Hp(0.07) represents 0.07 mm below the surface of the body (or a shallow dose). There are 1st and 2nd dose rate alarms, or personal dose equivalent per hour (Hp/h), for Hp(10)/h and a single dose rate alarm for Hp(0.07)/h. The dose-rate flags are not cleared automatically when the dose-rate falls below the reset threshold.

The 2nd alarm threshold (dose or dose rate) always has a higher priority than the 1st alarm threshold. The 1st alarm threshold can be considered as a warning value and the 2nd alarm threshold as a critical value. Therefore, the 2nd alarm threshold should always be set to the higher value.

Alarm thresholds are set via the IR communications link, or by the button if the user is granted authority, to any value in the following ranges. It is not recommended to set dose rate alarms to less than 10 mrem/h for Hp10/h or 1 rem per hour (rem/h) for Hp(0.07)/h as the statistical errors on the dose rate reading at these levels could be significant, and false alarms may subsequently occur.

Results of the EPD are real-time quantitative exposures and should be compared to applicable exposure guidelines (situation dependent) in support of HRAs. During use, the user has functional ability to scroll through the enabled displays to see the real-time dose and dose rate via the LCD screen.

The following checklist and procedures for the Mk2 series of EPDs (**EPD® Mk2**) are intended as quick reference guides.

EPD® Mk2 Issue and Return Checklist	√
PRE OPERATIONS	
Is the **EPD® Mk2** working and free of noticeable physical damage? No physical damage detected. No Default display showing on the LCD.	
Is the **EPD® Mk2's** calibration current? (Annual)	
Does the **EPD® Mk2** have the appropriate mounting device attached? - Is the lanyard or the belt-clip attached so it can be attached to the body?	
Has the **EPD® Mk2** conducted a successful confidence test?	
Has the **EPD® Mk2** been programmed to the appropriate dose and dose rate levels? (Situation Dependent)*	
Has the user's identification been entered into the EasyEPD®2 software?	
Has the user been instructed on the proper wearing of the **EPD® Mk2**, its purpose, and what to do in the event the alarm sounds? (i.e., Evacuate backwards to avoid blocking the dosimeter with the body.)	

EPD® Mk2 Issue and Return Checklist	√
PRE OPERATIONS	
Is the **EPD® Mkb2** attached to the body properly and not covered by any articles of clothing?	
POST OPERATIONS	
Has the **EPD® Mk2** been decontaminated?	
Has the **EPD® Mk2** been returned to the issuing unit, since work is complete?	
Per the user, did any alarms sound?	
Has the data been downloaded by the EasyEPD®2 software?	
Has the dose-of-record been recorded in an alternate log?	
Has the **EPD® Mk2** been cleared and prepared for the next user?	

* Refer to the Risk Assessment section below for determining appropriate levels for the situation.

Medical countermeasures

Ever since the terrorist attacks by flying commercial airline aircraft into the World Trade Center and the Pentagon on September 11, 2001 (9/11), the increased focus on terrorism has become a primary national security priority. There has also been increased awareness that terrorists might employ unconventional tactics and weapons, including WMD. Several terrorist threat scenarios could result in segments of the population being exposed to ionizing radiation. These include contamination of food or H_2O with RAM, placement of radiation sources in public locations, detonation of an RDD, and attacks on nuclear power plants or high-level nuclear waste storage facilities. The worst scenario would be the detonation of a nuclear explosive device.

To respond to these threats, the federal government is committed to increasing the availability of medical countermeasures that could be used in the aftermath of an attack involving the release of RAM. The US Department of Health and Human Services (HHS) tasked several federal government agencies to develop a robust research program on behalf of the National Institutes of Health (NIH) to accelerate the development and deployment of radiation/nuclear medical countermeasures for the Strategic National Stockpile and biodosimetry devices to be used in mass casualty radiation/nuclear incidents involving INDs or RDDs.

The primary treatment for internal contamination is to increase the rate of elimination of the radioactive isotope. This can be done by mechanical means (lung lavage) or through drugs that enhance removal. The decision to treat is based upon a balance between the severity of the internalization, the effectiveness of the treatment, and the risks of treatment. Seek assistance from USAFSAM to resolve these issues. The primary task for internal contamination is ensuring that appropriate bioassay procedures are initiated.

There are Food and Drug Administration (FDA) approved products available that increase the rate of elimination of other radioactive elements. They include the following:

Potassium iodide

Potassium iodide is the only FDA-approved medication available to treat contamination with radioactive iodine in various parts of the body, including the thyroid.

Radiogardase (Prussian blue insoluble capsules)

Radiogardase is approved to treat known or suspected internal contamination with radioactive cesium and/or radioactive or non-radioactive thallium to increase their rates of elimination. Prussian blue reduces the T_b of cesium from about 110 days to about 30 days and the T_b of thallium from about 8 days to about 3 days. Because Prussian blue reduces the time that radioactive cesium and thallium stay in the body, it helps limit the amount of time the body is exposed to radiation.

CAUTION: People *SHOULD NOT* take Prussian blue artist's dye to treat themselves. This type of Prussian blue is not designed to treat radioactive contamination.

Diethylene triamine pentaacetic acid

Diethylene triamine pentaacetic acid (DTPA) is a kind of medicine called a chelating agent. Chelating agents work by binding and holding on to RAMs or poisons that get into the body. Once bound to a RAM or poison, the chelating agent is then passed from the body in the urine. Chelating agents help decrease the amount of time it takes to get a poison out of the body. Calcium-diethylenetriamine pentaacetic acid (Ca-DTPA) and Zinc-Diethylenetriamine pentaacetic acid (Zn-DTPA) are approved to treat known or suspected internal contamination with plutonium, americium (Am), or curium to increase the rates of elimination. When given within the first day after internal contamination has occurred, Ca-DTPA is about 10 times more effective than Zn-DTPA at chelating plutonium, americium, and curium. After 24 hours have passed, Ca-DTPA and Zn-DTPA are equally effective in chelating these RAMs.

Ethylenediaminetetraacetic acid

Ethylenediaminetetraacetic acid (EDTA) is a chelation therapy treatment that involves repeated intravenous (IV) administration of the chemical solution. It is used to treat acute and chronic lead poisoning by pulling toxins (including heavy metals such as lead, cadmium, and mercury) from the bloodstream.

Control of contamination

Before determining what needs to be done to control contamination, is critical to understand the difference between *exposure* to radiation and *contamination* with RAM. The medical effects and countermeasures differ significantly.

Radiation exposure (or irradiation)

This occurs when *radiation* penetrates tissue; for example, when a patient undergoes a diagnostic X-ray, radiation penetrates tissue. A person can be irradiated without physically contacting RAM. Exposure from radiation external to the victim, radiation in the air or on the ground, does NOT make the victim a radiation hazard to response personnel.

Radioactive contamination

This is RAM located in unintended places. If people remain contaminated, they will continue to be exposed to the radiation emitted by the RAM. Contamination can be external (outside of the body), internal (inside of the body), or both.

- Internal contamination is RAM that has entered the body by inhalation, ingestion, injection, or absorption through the skin or wounds. Exposure from RAM internalized MAY make the victim a radiation hazard to response personnel.
- External contamination is RAM on a person's clothes, hair, or skin. Exposure from external RAM WILL make the victim a radiation hazard to response personnel.

After a radiological or nuclear event, personnel, equipment, vehicles, buildings, and the environment will be contaminated with RAM. However, a high priority for the initial response force is the rescue and treatment of casualties. Local ambulances and hospitals may be requested to evacuate and treat accident-related casualties. Treatment of life-threatening injuries should always take precedence over contamination considerations. Care should be taken to reduce the spread of contamination whenever possible and to avoid unnecessary contamination of medical resources when injuries are minor and adequate first aid is available. Therefore, casualties with non-life-threatening injuries should be surveyed for radiological contamination and decontaminated, as required, prior to evacuation and transport to medical facilities for treatment.

Officials at hospitals and clinics to which casualties are evacuated should be notified of the possibility of radioactive contamination so that proper measures can be taken. The medical decontamination team should be activated immediately upon notification of a radiological event; radioactive contamination is always suspected until proven otherwise. The medical facility should be prepared with an operational decontamination station with a physician, medical technicians, and litter bearers standing by to receive the casualties.

Patient decontamination

Whenever possible, partial or complete external decontamination of injured patients should be performed at the site. All contaminated clothing should be removed to help prevent further contamination. Ambulatory patients can frequently decontaminate themselves; however, they must be given suitable instructions and must be carefully monitored by personnel experienced in decontamination techniques and use of radiation survey instruments. If not ambulatory, the person should be thoroughly washed with soap or detergent.

Immediately upon arrival of the ambulance at the decontamination station, a physician should make the determination if decontamination of the patients is feasible or whether they should receive immediate medical treatment. The hazard from a radiologically contaminated casualty will be negligible, both to attending medical personnel and the facility, so necessary medical or surgical treatment must not be delayed because of possible contamination. The initial management of a casualty contaminated by radiological agents is to perform all immediate life- and limb-saving actions without regard to contamination (decontamination can always be performed later).

NOTE: Radiologically contaminated patients generally pose no danger to healthcare personnel. It is virtually impossible for a living patient to be so contaminated as to pose a threat to healthcare providers.

After emergency first aid has been administered to control hemorrhage and treat shock, the crucial first step in decontaminating wounds is to find the contamination. It is extremely important to check all wounds for contamination when skin contamination has been detected. It is also necessary to consider the possible chemical hazards of the compounds along with the radioactive contaminants, as well as bacterial or other microbiological contamination. For alpha emitters, detection can be difficult. In most cases, the removal of contamination, once found, presents no special surgical challenge; however, it does require considerable patience and perseverance.

It is important to recognize when the decontamination effort can be safely and wisely stopped. Citing an absolute numerical level would require many misleading assumptions. Typical questions that arise are: Is the contamination confined only to the superficial parts of the outermost layer? Has contamination penetrated uniformly throughout the layer, or has it already penetrated through to the basal layer? Removing outer clothing and shoes and rapidly washing exposed skin and hair removes 90% of contamination. If the contamination is on or near the surface, it will probably be sloughed in two or three days. If it is uniformly distributed throughout the outermost layer, the rate of sloughing will be similar to the turnover time of that layer, about 6 to 7% per day. The rate of the initial contamination, at least as far as absorption is concerned, depends on its physical and chemical characteristics. For these reasons, it is not realistic to set arbitrary radiation levels that would indicate whether to pursue additional decontamination.

It is always wise to remove as much contamination as possible without seriously irritating the skin. Most individuals will be apprehensive if they see a positive instrument reading and will not be satisfied with just a statement that such a count rate is inconsequential, and decontamination is not needed. Only after a reasonable effort has been made is it easier to convince the patient that further efforts are not necessary and might be counterproductive. In addition to patients or casualties, the physician and medical technicians on the ambulance should be processed through the decontamination station.

Personnel decontamination

There are two basic types of personnel decontamination stations. The first is a detailed decontamination station that is suitable for small affected populations and for processing response personnel into and out of the affected area. The second are decontamination stations established at community centers for large events. For large events there will be two types of contaminated personnel: those who are a high priority for decontamination and those whose decontamination can be delayed.

Passage of all persons and property between contaminated and clean areas must be surveyed and regulated by monitoring teams. Supplies are passed through monitoring stations from clean areas to contaminated areas. Reverse flow must not occur unless supplies are monitored and found clean. The entry of all nonessential personnel including family, visitors, and administrative persons should be restricted from decontamination facility.

Figure 4–22 shows the general layout for a screening and decontamination station for a large event. It is important to note that everyone who enters the station is sent through the same post-decontamination processes. It is particularly important that everyone be entered into the event registry. Each of the stations outlined in yellow will also need radioactive waste containers and the supplies required to bag and tag clothing and valuables.

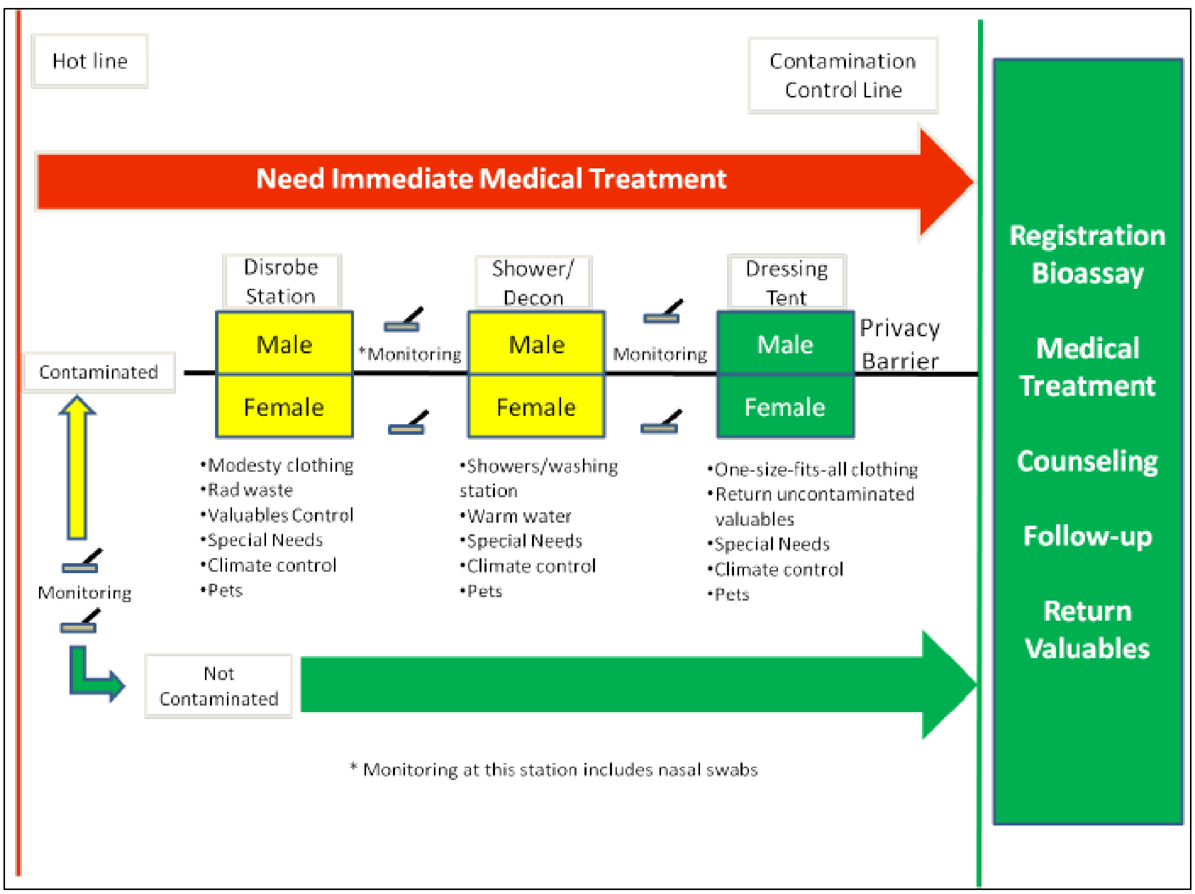

Figure 4–22. Notional Decontamination Station for Victims of a Large Event.

Many additional people will need at least rudimentary decontamination when they arrive at a location where they choose for shelter. Facilities will need to be identified that can provide thorough washing at or near community shelters and reception centers. In mass casualty incidents, it may not be possible to process many people quickly enough using portable decontamination facilities.

Effective decontamination of people from fallout is straightforward (remove clothes and shower). In cases of localized areas of contamination, such as the hands or face, these areas should be cleaned by washing the area with detergent and H_2O. In cases of more generalized contamination, the person should be instructed to shower. An initial shower can often be given near the accident site and the patient then moved to an emergency medical and decontamination area where more elaborate skin decontamination techniques can be used.

Contaminated materials and equipment

The floors should be protected with a disposable covering to reduce tracking and to aid the cleanup tasks. The covering should be changed when contamination levels exceed 300 cpm alpha. If the cover cannot be changed when this level is reached, use of respirator is required.

All contaminated clothing and waste should be placed carefully into labelled plastic or paper bags to reduce secondary contamination of area. Sponges and other waste material should not be disposed recklessly. Material objects from the wounds must be saved, and if separable from the rest of the waste, placed in specially marked bags. These fragments require special handling as they will be studied by technical experts from the national laboratories.

All contaminated materials should be collected and stored in an area that is established specifically for contaminated storage, and adequate security should be provided for the area. If BE identifies the contaminated material as having short-life, the material may be held in the storage area until decontamination is accomplished by aging and then treated as nonradioactive waste. The liquid waste, such as H_2O used in decontamination of personnel and equipment cannot be released into existing sewerage facilities until it has been determined that the isotope concentration is within the limits set up in Title 10 CFR Part 20.

Certain equipment, such as RADIAC meters, can be enclosed in plastic bags to reduce equipment contamination. Alpha-survey instrument probe faces must not be covered. Probes for instruments, such as the Field Instrument for the Detection of Low Energy Radiation (FIDLER), may be covered.

After all personnel decontamination has been completed, the decontamination station crew should monitor and decontaminate the ambulance and its equipment, if necessary. Ambulances, however, should be kept outside the cordoned and hot zone areas at all times. Therefore, when departing with casualties, ambulances will not be decontaminated prior to departure from the collection point. If an ambulance does become contaminated, decontamination procedures must be accomplished prior to transporting clean or decontaminated patients. Consideration should be given to decontamination standards for military equipment, which may differ from Federal or State standards. Acceptable surface contamination levels for certain isotopes can be found in in AFMAN 48–148, *Ionizing Radiation Protection*, Title 10 CFR 835, Appendix D, *Surface Contamination Values*, and *Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual (MARSAME)*, Nuclear Regulation (NUREG)–1575, Supplement 1.

The following table lists standards that should be applied to all small-scale accidents as well as incidents resulting from a practice.

Acceptable Surface Contamination Levels[1] (Bq/cm^2 and dpm/100 cm^2).

Nuclide	Removable[2,4]	Total (Fixed + Removable)[2,3]
U-nat, ^{235}U, ^{238}U, and associated decay products	[7] 1,000 dpm/100 cm^2 (0.17 Bq/cm^2)	[7] 5,000 dpm/100 cm^2 (0.83 Bq/cm^2)
Transuranics, ^{226}Ra, ^{228}Ra, ^{230}Th, ^{228}Th, ^{231}Pa, ^{227}Ac, ^{125}I, ^{129}I	20 dpm/100 cm^2 (0.0033 Bq/cm^2)	100 dpm/100 cm^2 (0.017 Bq/cm^2)
Th-nat, ^{232}Th, ^{90}Sr, ^{223}Ra, ^{224}Ra, ^{232}U, ^{126}I, ^{131}I, ^{133}I	200 dpm/100 cm^2 (0.033 Bq/cm^2)	1,000 dpm/100 cm^2 (0.17 Bq/cm^2)
Beta/gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except ^{90}Sr and others noted above[5]	1,000 dpm/100 cm^2 (0.17 Bq/cm^2)	5,000 dpm/100 cm^2 (0.83 Bq/cm^2)
Tritium and tritiated compounds[6]	1.7 Bq/cm^2 (10,000 dpm/100 cm^2)	N/A

Note: This table is extracted from Title 10 CFR 835, Appendix D and NUREG-1575, *Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual (MARSAME),* Supplement 1, Table E.1. In general, this table will not apply to contingency operations. For contingency operations follow the COCOM, or equivalent, directives.

1. The values in this appendix, with the exception noted in footnote 5, apply to radioactive contamination deposited on, but not incorporated into the interior or matrix of, the contaminated item. Where surface contamination by both alpha-and beta-gamma emitting nuclides exists, the limits established for alpha-and beta-gamma-emitting nuclides apply independently.

2. As used in this table, dpm (disintegrations per minute) means the rate of emission by RAM as determined by correcting the cpm observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

3. The levels may be averaged over one square meter provided the maximum surface activity in any area of 100 cm^2 is less than three times the value specified. For purposes of averaging, any square meter of surface shall be considered to be above the surface contamination value if: (1) From measurements of a representative number of sections it is determined that the average contamination level exceeds the applicable value; or (2) it is determined that the sum of the activity of all isolated spots or particles in any 100 cm^2 area exceeds three times the applicable value.

4. The amount of removable RAM per 100 cm^2 of surface area should be determined by swiping the area with dry filter or soft absorbent paper, applying moderate pressure, and then assessing the amount of RAM on the swipe with an appropriate instrument of known efficiency. (Note: The use of dry material may not be appropriate for tritium.) When removable contamination on objects of surface area less than 100 cm^2 is determined, the activity per unit area shall be based on the actual area and the entire surface shall be wiped. It is not necessary to use swiping techniques to measure removable contamination levels if direct scan surveys indicate that the total residual surface contamination levels are within the limits for removable contamination.

5. This category of radionuclides includes mixed fission products, including the Sr-90 which is present in them. It does not apply to Sr-90 which has been separated from the other fission products or mixtures where the Sr-90 has been enriched.

6. Tritium contamination may diffuse into the volume or matrix of materials. Evaluation of surface contamination shall consider the extent to which such contamination may migrate to the surface in order to ensure the surface contamination value provided in this appendix is not exceeded. Once this contamination migrates to the surface, it may be removable, not fixed; therefore, a Total value does not apply.

7. Alpha activity.

Precautions for decontamination are as follows:

- Soap, brushes, and other articles (equipment) used for decontamination may become contaminated during use and should be handled accordingly.

- Unnecessary exposure to radiation should be avoided under all circumstances.
- Wear appropriate protective clothing when surveying and decontaminating equipment; at a minimum, wear disposable gloves and booties.
- Care must be exercised to prevent contamination from spreading to other areas.
- Do not use decontamination methods that will spread localized materials or increase surface penetration.
- Personnel must refrain from eating, drinking, or smoking in any areas where monitoring or decontamination activities are being conducted.
- It is difficult for one person alone to carry out all monitoring and recording. Several references suggest a minimum of three members per team: one to monitor, one to record results, and one to deal with contaminated items or persons.

Management of contaminated bodies

As can be found in guides available for BE to respond to radiological emergencies, one aspect of personnel contamination control that is often ignored involves fatalities, which require monitoring. If only alpha radiation is involved, as much contamination as possible should be removed from the body prior to removal from the site. The key point to remember is that contamination should be localized where it already exists, and all efforts should be made to prevent it from spreading. If decontamination on-site is not feasible, a body bag (or an improvised container to completely surround the body) will suffice until such time decontamination can be accomplished. Decontamination techniques already described may be used, although the precautions against abrading the skin obviously do not strictly apply. Be careful not to disfigure the body any more than it already is from its involvement in the accident. Everybody should be treated with dignity, as you would if it were a member of your own family. The primary concern is minimizing the spread of contamination. Remember that the body will eventually be transferred to medical/mortuary personnel. These individuals, as well as relatives of the deceased, must all be protected.

Hasty decontamination is not required since radiation can no longer harm the deceased. If the contamination is deposited on the surface of the body, it can be hosed off at a distance, although care should be taken not to contaminate the local environment (assuming it is clean). After most of the contamination is removed, the decontamination techniques described previously may be employed. If the contamination cannot be removed (e.g., it is imbedded in the body as a result of an explosion), the body should be treated as a radioactive source and either isolated or shielded. In a disaster involving multiple fatalities, the medical examiner or coroner may establish a field morgue near the scene, particularly if the possibility of hazardous material contamination exists. A typical field morgue consists of an initial triage area and an examination table where evidence and personal effects can be recovered and documented. Establish the screening station outside the control point, with a table for the remains containers and body bags. A radiation technician, equipped with gloves and a survey meter, should perform the screening. Survey each body using the following guidelines:

Refrigeration unit

If a body reads greater than 100 mrem/hr with the probe 1 inch away, that body should be moved to a refrigeration unit at least 30 feet from the work area. This will prevent the morgue staff from exceeding their dose limits on the first few decedents and will allow the morgue staff to consult BE and devise a special work plan. If the source of the radiation is a mix of short-lived radioisotopes, it will allow radioactive decay to decrease the dose rate.

Regular morgue or uncontaminated field morgue

Decedents that have no external contamination above the specified limits can be transported to the regular morgue or to an uncontaminated field morgue for further processing. These are the only remains that require a complete survey—front and back, inside the remains container, and inside the body.

Field morgue

Remains that have measurable contamination below 100 mrem/hr at 1 inch should be sent to the field morgue. Prior to beginning processing, the RSO should establish administrative limits on workers' doses, based on the measured dose rates from the decedents and the number to be processed. This could be a total cumulative dose, such as 200 mrem for the entire operation; if the number of expected decedents is not yet known, it may be a limit such as 25 mrem per decedent.

The Centers for Disease Control and Prevention (CDC) has developed an extensive amount of information regarding radiation, both for the community at large, as well as for as professionals. These can be found at https://www.cdc.gov/nceh/radiation/default.htm. Further, they developed Guidelines for Handling Decedents Contaminated with Radioactive Materials, made available at https://www.cdc.gov/nceh/radiation/emergencies/pdf/radiation-decedent-guidelines.pdf. It suggests ways for medical examiners, coroners, and morticians to deal with loose surface contamination, internal contamination, or shrapnel on or in decedents' bodies following the detonation of a nuclear weapon or activation of a RDD. These guidelines can be used to help control exposures when dealing with decedents.

General precautions for decontamination

The following list provides general precautions for decontamination.

- Soap, brushes, and other articles (equipment) used for decontamination may become contaminated during use and should be handled accordingly.
- Unnecessary exposure to radiation should be avoided under all circumstances.
- Wear appropriate protective clothing when surveying and decontaminating equipment. At a minimum, wear disposable gloves and booties.
- Care must be exercised to prevent contamination from spreading to other areas.
- Do not use decontamination methods that will spread localized materials or increase surface penetration.
- Personnel must refrain from eating, drinking, or smoking in any areas where monitoring or decontamination activities are being conducted.
- It is difficult for one person alone to carry out decontamination, monitoring, and recording. Several references suggest a minimum of three members per team, though larger teams are generally more effective.

Contaminated food and water

The FDA has guidance on acceptable levels of radioactive contamination in food known as derived intervention levels (DIL) and is entitled *Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies.* It is available at the FDA's web site https://www.fda.gov/regulatory-information/search-fda-guidance-documents/accidental-radioactive-contamination-human-food-and-animal-feeds-recommendations-state-and-local.

This guidance provides a method for calculating the DIL for a specific radionuclide based on a limiting radiation dose to an individual consuming food contaminated at the level of a DIL for a period of one year. This guidance has been adopted by many states for their nuclear power plant safety programs and has been incorporated into the EPA's PAG Manual. The FDA's representatives on the Advisory Team for the Environment, Food, and Health, along with Center for Food Safety and Applied Nutrition, radiation subject matter experts assist with the interpretation of the guidance.

DILs are limits on the concentrations permitted in human food distributed in commerce. They are established to prevent consumption of undesirable amounts of radionuclides and have units of radionuclide activity per kg of food; that is becquerels per kilogram (Bq/kg). Picocuries per kilogram (pCi/kg) were the units previously used. DILs apply during the first year after an accident. If there is concern that food will continue to be significantly contaminated beyond the first year, the long-term circumstances need to be evaluated to determine whether the DILs should be continued or if other guidance may be more applicable.

The FDA recommendations established two levels of PAGs. These were defined as “projected dose commitment values to individuals in the general population that warrant protective action following a release of RAM.” The lower level, called the Preventive PAG, was a projected dose commitment of 5 mSv (0.5 rem) to the whole body, active bone marrow, or any other organ except the thyroid, or a projected dose commitment of 15 mSv (1.5 rem) to the thyroid. The Preventive PAG was associated with low impact protective actions (e.g., placing dairy cows on stored feed).

The upper level, called the Emergency PAG, was a projected dose commitment of 50 mSv (5 rem) to the whole body, active bone marrow, or any other organ except the thyroid, or a projected dose commitment of 150 mSv (15 rem) to the thyroid. The Emergency PAG was associated with higher-impact protective actions (e.g., diversion of fresh milk to cheese or milk powder).

Following the Chernobyl accident in 1986, a task group of representatives from the FDA and the Food Safety and Inspection Service (FSIS) of the United States Department of Agriculture (USDA) established DILs for application to imported foods under their respective regulatory control. The FDA DILs were called “levels of concern” (LOC) and the FSIS DILs were called “screening values.” If food contained concentrations below the LOCs and screening values, it was permitted to be imported into the US. FDA LOCs were derived from the 1982 Preventive PAGs and used the following assumptions.

- The entire intake of food would be contaminated.
- Iodine–131 (I–131) could be a major source of radiation dose for only 60 days following the accident.
- Cesium–134 (Cs–134) + Cs–l37 could be a major source of radiation dose for up to one year.

The LOCs provided such a large margin of safety that derivation of LOCs for other radionuclides, judged to be of less health significance, was considered unnecessary. The FDA and FSIS DILs for the Chernobyl accident contamination in imported food after November 1986 are provided in the following table.

	FDA LOC		FSIS Screening Value
Radionuclide	**Infant Food**	**Other Food**	**Meat and Poultry**
I–131	55 (1500)	300 (8000)	55 (1500)
Cs–134 + Cs-l37	370 (10,000)	370 (10,000)	370 (10,000)

The types of accidents and the principal radionuclides for which the DILs were developed are provided in the following list:

- Nuclear reactors (I–131; Cs–134 + Cs-l37; ruthenium [Ru-l03 + Ru–106]).
- Nuclear fuel reprocessing plants include Sr–90; Cs–137; Pu–239 + americium–241 (Pu–239 + Am–241).
- Nuclear waste storage facilities (Sr–90; Cs–137; Pu–239 + Am–241).
- Nuclear weapons (i.e., dispersal of nuclear material without nuclear detonation) (Pu–239).
- Radioisotope thermoelectric generators and radioisotope heater units used in space vehicles (Pu–238).

The radionuclides listed are expected to be the predominant contributors to radiation dose through ingestion. Several radionuclides could be released by an accident at a nuclear reactor, a nuclear fuel processing plant, or a nuclear waste storage facility, while only the specific radionuclide used in a nuclear weapon or a space vehicle would be released in that type of accident. When more than one radionuclide is released, the relative contribution that a radionuclide makes to radiation dose from ingestion of subsequently contaminated food depends on the specifics of the accident and the mode of release (NRC 1975, DOE 1989, EPA 1977).

The DILs were based on the entire diet (including tap H_2O used for drinking) for each age group, not for individual foods or food groups. The calculation presumed that contamination would occur in 30% of the dietary intake. The value of 30% was based on the expectation that normally less than 10% of the annual dietary intake of most members of the population would consist of contaminated food. An additional factor of three was applied to account for limited subpopulations that might be more dependent on local food supplies. An exception was made for I–131 in the diets of the 3-month and 1-year age groups, where the entire intake over a sixty-day period was assumed to be contaminated.

Contamination released by an accident should not usually affect the safety of public H_2O systems with adequate H_2O treatment capability. Radioactive H_2O that does enter the body is chemically identical to ordinary H_2O and is distributed throughout the body tissues. The body usually eliminates and renews 50% of its H_2O in about 8 to 12 days. This T_b varies with fluid intake. Its time in the body may be significantly reduced by increasing the fluid intake. Under medical supervision, the T_b may be reduced to 3 days. Without medical supervision, a recommended procedure is to have the patient drink 1 quart of H_2O within 1-half-hour of exposure. Thereafter, maintain the body's H_2O content by drinking the same amount as excreted until medical assistance is obtained.

In CONUS, final determinations for drinking H_2O quality must be made in coordination with state offices for H_2O quality since they have primacy. For overseas and deployed bases, the final governing standards (FGS) or Overseas Environmental Baseline Guidance Document (OEBGD) should be used as the standard. DODM 4715.05, Volume 3, *Overseas Environmental Baseline Guidance Document: Water*, states that an installation responsible for a community H_2O system will test the system for conformance with the applicable radionuclide limits presented in the following table:

Contaminant	MCL
Gross alpha[1]	15 pCi/L
Combined Radium–226 and –228	5 pCi/L
Beta particle and photon radioactivty[2]	4 mrem/yr
Uranium	30 µg/L

Notes:

1. Gross alpha activity includes radium–226 but excludes radon and uranium.

2. Beta particle and photon activity is also referred to as gross beta activity from manmade radionuclides.

Monitoring Requirements:

All CWSs using ground H_2O, surface H_2O, or systems using both ground and surface H_2O must sample at every point (i.e., sampling points) in the distribution system that is representative of all sources being used under normal operating conditions.

For gross alpha activity and radium–226 and radium–228, systems are tested once every four years. Testing is conducted using an annual composite of four consecutive quarterly samples or the average of four samples obtained at quarterly intervals at a representative point in the distribution system.

Gross alpha only may be analyzed if activity is <5 picocuries per liter (pCi/L). Analyses should be performed when activity is >2 pCi/L where radium–228 may be present, radium–226 and/or –228 If the average annual concentration is less than half the MCL, analysis of a single sample may be substituted for the quarterly sampling procedure. A system with two or more sources having different concentrations of radioactivity shall monitor source H_2O in addition to H_2O from a free-flowing tap. If the installation introduces a new H_2O source, these contaminants are monitored within the first year after introduction.

It is important, however, to recognize that these limits are set for ‘normal’ conditions. For short duration emergency operations, these standards may be adjusted by health physics experts. Food and H_2O sampling during an incident must be done under the guidance of specialized teams, such as the AFRAT. These teams have specialized equipment for testing food and H_2O for radiologic contamination and will be able to give specific instructions on how samples must be collected.

Protective actions

Protective actions are steps taken to limit the radiation dose from ingestion by avoiding or reducing the contamination that could occur on the surface of, or be incorporated into, human food and animal feeds. Such actions can be taken prior to and/or after confirmation of contamination. The protective actions for a specific accident are determined by the particulars of the situation and once initiated they continue at least until the concentrations are expected to remain below the DILs.

Protective actions which can be taken within the area likely to be affected and prior to confirmation of contamination consist of the following:

- Simple precautionary actions to avoid or reduce the potential for contamination of food and animal feeds.
- Temporary embargoes to prevent the introduction into commerce of food which is likely to be contaminated.

Protective actions can be taken before the release or arrival of contamination if there is advance knowledge that radionuclides may accidentally contaminate the environment. These can be accomplished for downwind areas if effective plotting is accomplished in a timely manner. Precautionary actions should be implemented to avoid placing in jeopardy persons implementing the action.

Sampling strategy

There are multiple steps in accomplishing successful sampling. First, the need or driver for laboratory sampling must be identified. This can be driven by a regulatory requirement or by the need for data. For example, an unknown source is found and requires identification before it can be properly disposed. At this point, the number of needed samples and their locations should be identified. Figure 4–23 outlines the radiation sample planning processes. Three key steps in the process are determining the AL, selecting the type of analysis, and interpreting the results.

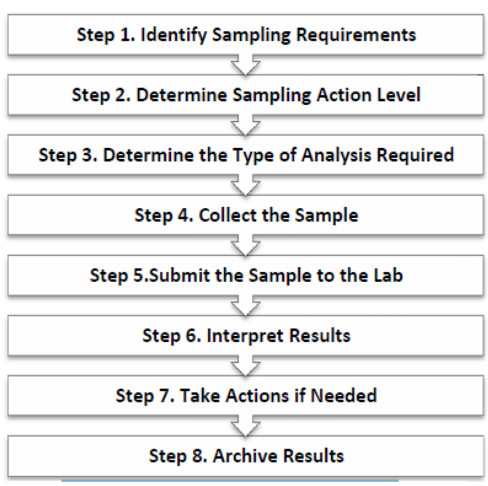

Figure 4–23. Radiation Sampling Processes.

Action level

Before a sample is submitted, there should be an AL associated with each sample. An AL is the point at which a sample result will initiate some action being taken or some level of concern or risk being identified. However, there are occasional samples that are only a measure of risk, and will not require an AL.

Type of analysis

Next, determine the type of analysis to be performed. The analysis performed must be sensitive enough to comply with any regulatory requirements or to identify an associated risk to a satisfactory level.

Results interpretation

The results of the analysis must be compared to an AL and interpreted.

The overriding supposition for all radiological monitoring is to assume the entire accident site is potentially contaminated and then prove radioactive contamination is either not present or locate and control any contamination present. Documentation of any monitoring should be kept and should include who did the monitoring, what instruments were used, where and when the monitoring was performed, and the actual measurements made.

Environmental sampling

Environmental sampling is conducted during the site remediation phase of the cleanup operation. Site remediation is the phase of accident response that addresses cleanup of contamination that may have occurred as a result of the accident and restoration of the affected area to conditions agreed upon by the stakeholders. Site remediation should be integrated into every phase of accident response. Preventing or mitigating the spread of contaminants is a high priority for the IC throughout the response.

The collection of environmental samples will be dictated by the type of environment where the accident occurs. Emphasis should be placed on anything that may enter the human food chain either directly or indirectly. Background samples should also be collected upwind to determine normal radiological levels. Specific types of sample to be collected can be found in and the *Bioenvironmental Engineer's Guide to Radiological Emergencies* found on the ESOH Service Center radiation web site

Air, soil, H_2O, vegetation, and wipe sampling of hard surfaces is required. Sampling should be initiated in the contaminated area soon after the accident. Samples must also be taken at locations remote from the contaminated area to verify background readings. After this, samples are required periodically during the recovery process to determine RAM migration and dispersion and to substantiate decontamination and/or recovery completion.

Airborne Radioactive Contamination

Airborne radioactivity following accidents in which radionuclides are in excess of permissible concentrations poses a serious threat to personnel and property. Air sampling is conducted to determine if airborne contamination is present. A cautious approach where RAMs in air are suspected can prevent the unfortunate consequences of unnecessary internal radiation exposure. Air sampling provides a basis for estimating the radiation dose and/or exposure that people without respiratory protection may have received and should be performed as soon as practical.

The purpose of any program of sampling airborne RAM is to determine the airborne concentration of radioactivity to which individuals may be exposed. Air sampling data are compared to the permissible limits of intake of RAM which are based on permissible radiation doses to the body and/or its organs. How well this data can be related to a hazard depends on certain variables. These include the accuracy of the sample volume, the accuracy of the counting equipment, and the accuracy of interpretation of the results.

If it can be shown that RAM has not been released from a weapon, then air sampling can be discontinued. However, if a Broken Arrow has occurred, air sampling should be continued until all measurable surface contamination has been removed, and all air samples are at background level.

Particulate sampling (e.g., plutonium and uranium compounds or fission fragments such as Cs–137 or Sr–90) is evaluated by passing a known volume of air through a filter. The filter media selected is extremely important if the measured radioactivity level is to be accurate. For those particles that will deposit in the lungs, the filter selected must have a high collection efficiency, up to 10 μm effective diameter. The filter should not be too porous since particulates will become deeply embedded, and self-absorption of alpha particles by the filter paper will result, with consequent reduction in counting efficiency.

It would be very useful to know the size of the particles being collected to determine respirability. Unfortunately, accurate particle size analysis is very difficult, and there is no satisfactory field method for making accurate determinations; therefore, airborne contamination should be assumed to be in the respirable range.

Placement of air samplers upon arrival at the scene of an accident and the proper recording of data received from them are important factors in the assessment of any hazardous condition due to airborne radioactivity. It is necessary to exercise careful judgment in selecting sampling locations to assure that the samples taken are the most representative possible. Initial placement of air samplers will differ from placement after the situation at the accident site has been stabilized. The purposes of initial placement of samplers are to ascertain the impact of the accident upon the area surrounding the site.

During the initial response, air samples should be collected at the control point, and at a point every 90° around the cordon, for a total of four samples. Air Sampler Number 1 is placed in a clear area beyond the fragmentation range, up to several hundred meters upwind from the accident site, for example, in the vicinity of the CP—to obtain a background air sample. This will provide a measure of the naturally occurring radioactivity, assuming the sample is free of weapon's contamination. When applying air sampling data to protection standards, this background radioactivity should be subtracted from the calculated airborne contamination. The samplers are placed facing (the filter side) upwind.

Additional air samplers should be placed at various ranges and quadrants downwind, including populated areas, to provide a more complete data base. Downwind samplers should be operated until it can be determined that there is no airborne contamination at their locations. An important consideration which should not be overlooked is that the sampling locations should be changed as wind directions change. When recording air sample data, the following information should be included:

1. Location of sampler.
2. Average flow rate (cfm).
3. Date and sampling start and stop times.
4. Type of filter paper.
5. Wind direction and weather conditions.
6. Measuring device (RADIAC instrument) and activity measured (cpm).
7. The time the measurement was made with the RADIAC instrument.

The length of sampling time (i.e., the sampling period) will vary depending on the objective. In order to properly respond to emergencies, or to determine the type of respiratory protection required initially, spot samples are usually taken. These may be samples of relatively short duration, for example, 10 to 30 minutes. Continuous samples are usually taken for 2 hours or more. They give an indication of the average concentrations to which individuals may have been exposed.

It is imperative that the sampling time be the same for all samples collected. It is not critical, however, that the sampling start and stop times be the same. The requirement for identical sampling times is based on the fact that natural radiation, namely radon and thoron daughters, collected on filters is a function of the sampling time.

Personal samplers

It is unlikely that personal monitors will be used to any degree during the initial phases of the response/recovery operations because of the requirement to use respirators for protection against the potential inhalation. Personal monitors are used when the objective is to determine the concentration of airborne contamination a person might have breathed (e.g., if used while a respirator is being worn), or most probably breathed (e.g., when working without respirators).

Nuclear dispersion hazards

Nuclear dispersion plotting is conducted to determine the extent of contamination from any radiological event. It is important to remember that any plotting is an estimate and should only be used as a starting point for identifying where sampling should be done.

Computer modeling is the fastest and least costly radiation dose estimate method in terms of resources required. There are multiple computer models capable of estimating both internal and external dose as a function of event parameters (nuclear detonation, RDD, etc.), isotope(s) used, weather, terrain, time, and distance from the event. The primary advantages of computer modeling are the speed with which the modeling can be accomplished and the large areas that can be assessed. The primary disadvantage is the potential for inaccurate assessments because of limitations of the model and the lack of information.

Types of plots

BE team members should be familiar with the CBRN planning and incident response procedures contained in the Installation Emergency Management Plan (IEMP) 10–2, described in AFMAN 32–1007, *Readiness and Emergency Management (R&EM) Flight Operations*, and in AFI 10-2501, *Emergency Management Program*. The BE team should plan for integrated response with other installation and off-installation response teams as appropriate.

CE is the primary facilitator for on-scene command, control, and communications. They provide initial hazard determination (hazard plot and/or initial agent detection). The BE team may use hazard plots/data provided by CE to refine CBRN hazard identification and quantification.

The BE team provides follow-on assessments and has equipment and skill sets for identifying and quantifying hazards. It is critical for the BE team and other responders to share information and interact in the form of training and exercises to ensure team interoperability. Team capabilities are maximized when these organizations work together during a CBRN response.

Numerous plots are available for disaster response planning. The programs most likely to be encountered during a radiological incident include the following:

- Atmospheric Release Advisory Capability (ARAC).
- Interagency Modeling and Atmospheric Assessment Center (IMAAC).
- Hazard Prediction and Assessment Capability (HPAC).

Atmospheric Release Advisory Capability

The ARAC provides real-time computer modeling to assess events involving the release of hazardous radiological materials into the atmosphere. The ARAC's centralized computer-based system provides realistic plots, or maps, of potential radiation dose and exposure assessments, and estimates of the path of nuclear contaminants released into the atmosphere. The ARAC capability may deploy 2–6 hours after notification, providing health and safety consequences using real-time meteorological data in a 3-D computer model and consequence forecasts out to 2 days into the future. Further information may be found at the National Atmospheric Release Advisory Center's (NARAC) web site http://narac.llnl.gov.

This web site includes the *hotspot*, which is a hybrid of the well-established Gaussian plume model, widely used for initial emergency assessment or safety-analysis planning. Virtual source terms are used to model the initial atmospheric distribution of source material after an explosion, fire, resuspension, or user-input geometry. Hotspot incorporates both FGRs 11 and 13 dose conversion factors (DCF) for inhalation, submersion, and ground shine. In addition to the inhalation 50-year CEDE DCFs, acute (24-hour) DCFs are available for estimating nonstochastic effects. This acute mode may be used to estimate the immediate radiological impact associated with high acute radiation doses (applicable target organs are the lung, small intestine wall, and red bone marrow). Individual target organ doses are optionally output by Hotspot, which supports both classic units (rem, rad, Ci) and International System units (Sv, Gy, Bq). Users may add radionuclides and custom mixtures (up to 50 radionuclides per mixture). The graphical (fig. 4–24) output consists of dose and ground contamination as a function of plume centerline downwind distance and radiation dose and ground contamination contours. Radiation dose and ground contamination contours may also be saved as mapping files for display on geographical maps.

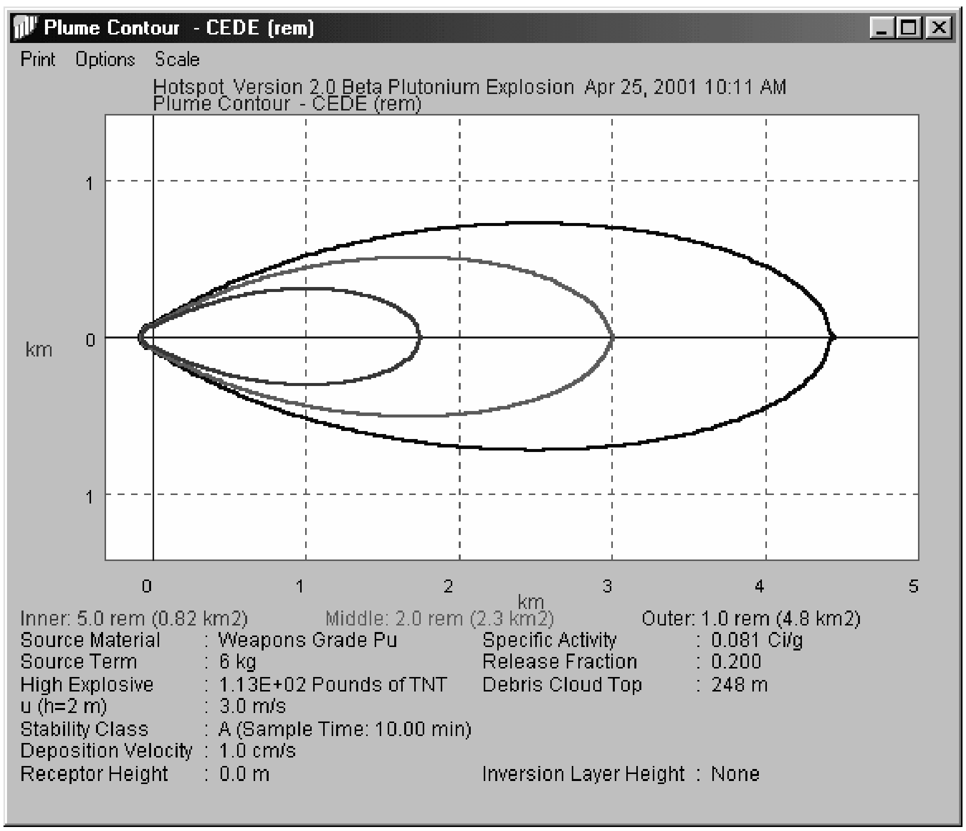

Figure 4–24. Hotspot Plume Contour.

Hazard Prediction and Assessment Capability

The HPAC provides a forward deployable modeling capability available for government, government-related, or academic use. This software tool assists in emergency response to hazardous agent releases. Its fast running, physics-based algorithms enable users to model and predict hazard areas and human collateral effects in minutes. The HPAC (fig. 4–28) can predict the effects of HAZMAT releases into the atmosphere and their impact on civilian and military populations.

The HPAC software uses integrated source terms, high-resolution weather forecasts, and particulate transport to model hazard areas produced by accidents. One of the HPAC's strengths is fast access to real-time weather data through meteorological data servers (MDS). The HPAC also has embedded climatology or historical weather for use when real weather is not available.

The HPAC models nuclear collateral effects of concern that may result from military or industrial accidents and provides source information on potential radioactive releases from nuclear weapons or reactor accidents. Terrain may have a large effect on where a HAZMAT is transported. In addition to working with a variety of weather data types, the HPAC works with two types of terrain data. By default, the HPAC assumes a flat earth for the terrain, and this may be a reasonable approximation for small spatial domains; however, users may choose to employ complex, 3-D terrain data describing the topographic variations. When the complex terrain option is used, it automatically invokes a mass consistent wind and turbulence model that is embedded within the HPAC.

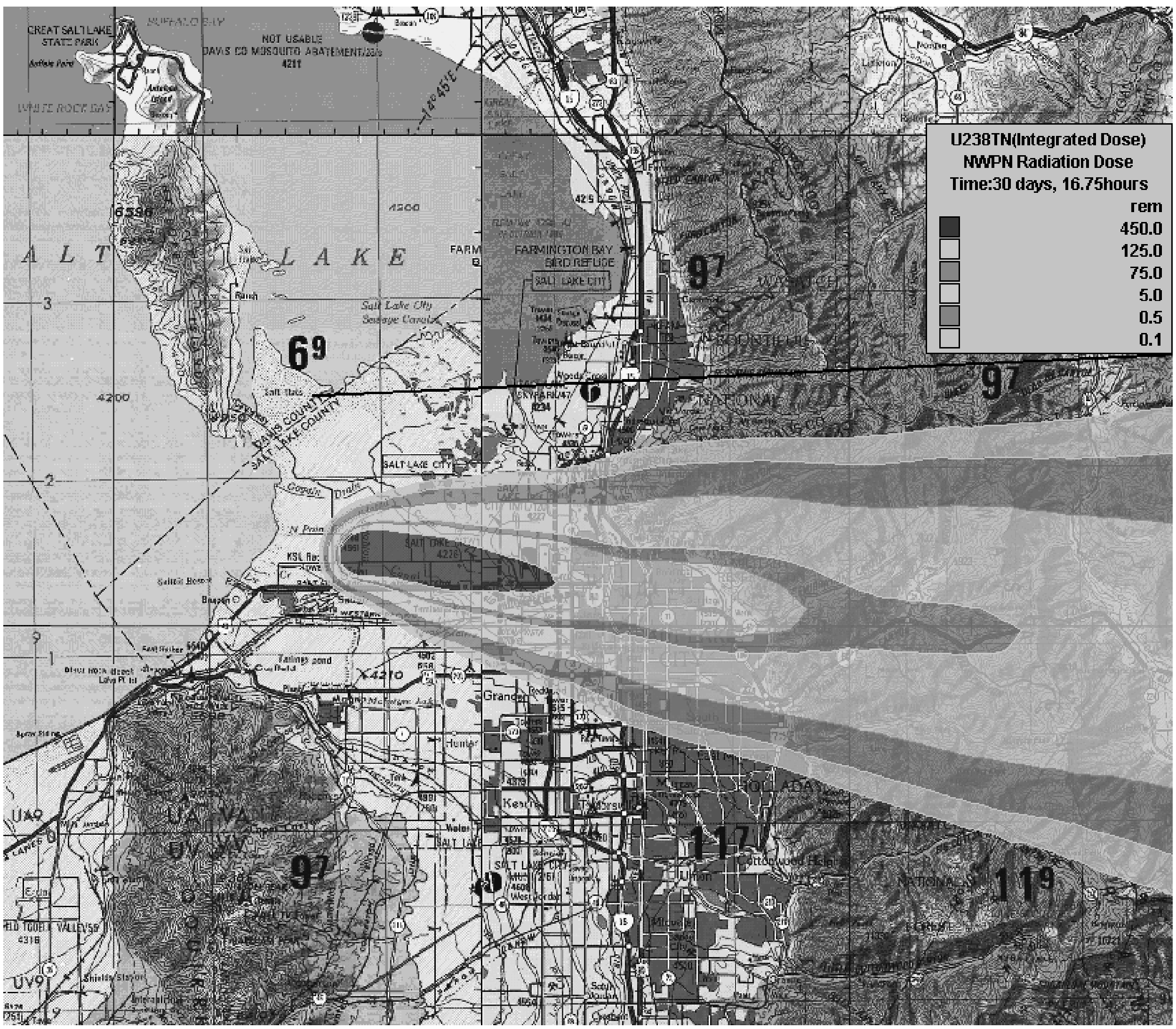

Figure 4–25. HPAC Plot.

Interagency Modeling and Atmospheric Assessment Center

The IMAAC is an interagency center responsible for production, coordination, development, and distribution of consequence predictions for an airborne HAZMAT release. The IMAAC generates the single federal prediction of atmospheric dispersions and their consequences, using the best available resources from the federal government. When notified of a US nuclear weapon accident, Defense Threat Reduction Agency (DTRA) activates its consequence management advisory team (CMAT). In addition to deploying to advise the DOD IC on technical issues, the federal response mechanism, and specialized teams' capabilities, the CMAT independently or with DTRA reachback resources will generate hazard area predictions based on reported source term information and release characteristics using forecasted numerical weather predictions. For domestic accidents, DTRA operates the IMAAC. DTRA must coordinate hazard area atmospheric predictions via IMAAC to provide the federal interagency-coordinated hazard area model. The IMAAC is nominally the single federal source of airborne hazard predictions in domestic incidents supporting the National Response Framework (NRF) and tasked with necessary federal coordination.

Before conducting any plotting, ask about local weather history and current forecasts to determine the best location for assets and minimize relocation of key activities due to changes in wind direction. This information will then be put into a plotting tool to produce a predictive model to help the IC in the decision-making process.

Request, receive, and use IMAAC hazard predictions. In the interim, first responders must use organic HPAC modeling tools with DTRA reach-back, or stand-alone HPAC systems for internal planning only. Use these plots until IMAAC plots are available. Once available, IMAAC plots supersede all others.

In general, high-risk decisions (general population evacuation, cessation of critical military operations) should not be made based solely on unconfirmed computer modeling. Confirmation requires on-the-ground measurements. Key information required includes the following:

1. The isotope and isotope type (penetrating radiations or non-penetrating).
2. Method of dispersal.
3. Size of blast, if resulting from a bomb.
4. And accurate weather information.

Risk assessment

From the outset, concern exists about the potential health hazard to the general public, particularly to those persons residing near the accident site. Considering possible radiation exposures is the primary method of estimating the potential health hazard. If no beta and/or gamma radiation is present, the primary risk is inhalation of alpha emitters that may cause a long-term increase in the likelihood of radiation-related diseases.

Initial hazard assessments shall, of necessity, be based on limited information, assumptions, and worst-case projections of possible radiation doses received. Actions in the initial response phase are focused on assessing the magnitude of the incident, establishing control zones, and facilitating the continuance of critical missions. The ARAC and HPAC models provide theoretical projections of the maximum internal radiation dose people may have received if outdoors and without respiratory protection from the time of release to the effective time of the predictive plot. Exposure to resuspended contaminants usually results in doses that are a small fraction of the dose that would be received from exposure to the initial release for the same time period.

The general public guidelines are 100 mrem/year dose equivalent from normal radiological operations. Early phase PAGs recommend evacuation during an emergency when one additional rem of projected dose could be avoided by evacuation. One rem corresponds to an airborne concentration of approximately 31.67 dpm/m^3 of ^{239}Pu for one week (168 hours). Personnel may be allowed to enter an area of higher activity without respiratory protection for a short period of time without exceeding regulatory dose equivalent limits (10 rem for protection of property, 25 rem for protection of personnel, and >25 rem for protection of personnel on a voluntary basis by personnel fully briefed on the associated risk of receiving >25 rem).

Radiologic Missions

The following key points need to be kept in mind when conducting a risk assessment:

- Each risk assessment examines the human risks (personnel training level, health), media (weather, terrain, hygienic conditions, and manmade structures), machine (instrumentation, logistics, airframes), mission, and management (standards, procedures, and controls).
- AF policy and guidance provides the framework for determining when RM should be based primarily upon individual risk—a practice—and when it should be based primarily on mission accomplishment—an intervention.
- The framework for radiation RM depends upon whether the mission is a practice or an intervention. If the mission is considered a practice, regulatory requirements and consequences of failing to meet them form the basis for assessing the severity associated with a given personnel exposure.
- The operational risks for a practice are primarily exceeding regulatory requirements for exposure to the worker, public, and the environment. The operational risks for an intervention may include exceeding exposure levels that may result in direct harm to responders.
- The severity for operations intended to reduce the effects of radiation is divided into that for the general public and that for responders. Both are based upon preventing acute effects. A catastrophic dose is one greater than the dose where acute effects are initiated (greater than 75 centigrays [cGy]).
- The severity for operations hindered by the presence of radiation (firefighting, rescue, peacekeeping, and combat) is based upon the type of operation and the importance of the operation. For combat operations, severity is based upon impact of the dose on immediate performance. Doses less than 75 cGy are considered negligible because performance is not degraded.
- Military operations during hostile actions are significantly different than responses to accidents and require additional guidance because of the nature of combat risk.
- A split operational exposure guidance (OEG) methodology will be used for base operations similar to the split mission-oriented protective postures (MOPP) concept.
- Acute radiation health effects occur at doses in excess of 75 cGy. These are health effects that occur rapidly and will degrade performance and impact mission accomplishment.

Radiation Exposure Status

The radiation exposure status (RES) is a system for categorizing a unit's radiation exposure level and providing guidance for the protection and surveillance actions required for units at these levels. The RES categories taken from Joint Publication (JP) 3-11, *Operations in Chemical, Biological, Radiological, and Nuclear (CBRN) Environments*, are presented in the following table.

Total Cumulative Doses[1]	RES Category	Recommended Protection and Surveillance Actions[2]	Increased Risk of Long-Term Fatal Cancer[5]
0 to 0.05 cGy **(0 to 0.05 rad)**	R0	None	Negligible
0.05 to 0.5 cGy **(0.05 to 0.5 rad)**	R1A	Record individual dose. Initiate periodic environmental monitoring.	1:4,000 (0.025%)
0.5 to 5 cGy **(0.5 to 5 rad)**	R1B	All actions for Category R1A plus: • Initiate radiation survey. • Prioritize tasks. • Establish dose control measures during operations.	1:400 (0.25%)
5 to 10 cGy **(5 to 10 rad)**	R1C	All actions for Category R1B plus: Execute priority tasks only[3].	1:200 (0.5%)
10 to 25 cGy **(10 to 25 rad)**	R1D	All actions for Category R1C plus: Execute critical tasks only[4].	1:80 (1.25%)
25 to 75 cGy **(25 to 75 rad)**	R1E	All actions for Category R1D plus: Execute critical tasks only[4].	1:30 (3.3%)
75 to 125 cGy[6] **(75 to 125 rad)**	R2	All actions for Category R1E plus: Any further exposure exceeds moderate operational risk.	1:20 (5%)
> 125 cGy **(> 125 rad)**	R3	All actions for Category R2 plus: Further exposure will exceed the emergency operational risk.	> 1:20 (5%)

1. The use of the measurement millisieverts (mSv) is preferred in all cases. For low LET, whole body irradiation (X-rays, gamma rays): 1 cGy =10 mGy = 1 rad≈10mSv≈1 R.

2. All doses should be kept ALARA. This will reduce individual risk as well as retain maximum operational flexibility for future employment of exposed personnel.

3. Examples of priority tasks are missions to avert danger to persons or to prevent further damage.

4. Examples of critical tasks are those missions to save lives.

5. This is in addition to the 1:5 and 1:4 incidence of fatal cancer among the general population. Increased risk is given for induction of fatal cancer. Total lifetime risk is assumed to be 4–7% per ~1,000 mSv (100 rad). It must be recognized that higher radiation dose rates produce proportionally more health risks than the same total dose given over longer periods of time.

6. NATO Standardization Agreement (STANAG) 2083, Commander's Guide on Nuclear Radiation Exposure of Groups, states 125 cGy (125 rad) as the commander's upper dose limit.

Operational exposure guidance

Selection of OEG can be made based upon the mission type and importance. The following table provides OEG for determining mission importance as it directly applies to combat operations; the information in the table can also be applied to other types of operations.

Mission	Description
Critical	Essential to the overall success of a higher headquarters' operation, emergency lifesaving missions, or like missions
Priority	Avert danger to persons, prevent damage from spreading, or support the organization's mission-essential task list
Routine	All other missions

Figure 4–26 shows the OEG as well as the guidance upon which it was based. For a practice, it is important to remember that there are also standards for the general public. The US EPA/US DHS PAGs are appropriate for missions whose focus is reducing a population's exposure. Appropriate OEG for missions hindered by radiation are outlined in red, yellow, and white.

Mission Importance / Acceptable Risk Level	Critical (cGy, rad)	Priority (cGy, rad)	Routine cGy, rad
Extremely High	125	75	25
High	75	25	5
Moderate	25	5	.05
Low	5	.05	.05

Combat OEG

PAGS

Practice & PAGS

Figure 4–26. Operational Exposure Guidance.

The OEG for a theater/mission should be set based upon the types of actions that are anticipated. A theater/mission where combat operations are anticipated can have any of the OEG levels selected. For a theater/mission where only actions to reduce dose are anticipated, an OEG of 25 cGy or less is appropriate. For a theater/mission where only practices are anticipated (humanitarian assistance), an OEG of 5 cGy or less is appropriate. Additional guidance for specific operations can be found in the Bioenvironmental Engineer's Guide to Radiological Emergencies found on the ESOH Service Center web site (https://hpws.afrl.af.mil/dhp/OE/ESOHSC/pages/index.cfm?id=428).

The hazard assessment must be followed quickly by recommending precautionary and safety measures to protect the public from exposure. To control and reduce exposure, radioactive contaminants must be prevented from entering the body and confined to specific geographic areas so that the contamination may be removed systematically. Methods for reducing the exposure to the public should be implemented by, or through, civil authorities and/or officials.

Documentation

Finally, all risk assessment measures, hazards encountered, protective measures taken, doses received, and decontamination performed must be documented. According to AFI 48–145, *Occupational and Environmental Health Program*, OEHSAs supply data for the Occupational and Environmental Health Exposure Data and is the form or report used for communicating exposures, establishing medical monitoring requirements, and are the inputs into the LER. AFI 48–145 also requires data to be maintained in the approved BE management information systems, currently Defense Occupational and Environmental Health Readiness System-Incident Reporting (DOEHRS–IR) for radiation. The OEHSA, via the HRA, provides the information that enables the commander's RM decision-making. Ultimately, during a radiological accident/incident, the BE mission is to give commander's timely information to make decisions, and then document health risks for medical personnel to address the consequences of those decisions.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

644. Theory and operation of nuclear weapons

1. Why is credible nuclear deterrence essential to US security?

2. What are the three global delivery platforms for nuclear weapons?

3. What is the AF nuclear enterprise?

4. What is a fundamental difference and similarity between nuclear and conventional explosions?

5. What is a nuclear chain reaction?

6. What is most of the energy of a nuclear weapon used to produce?

7. What effect of a nuclear explosion causes the most damage?

8. What effect does weather have on the impact of thermal radiation?

9. What is initial radiation and how long does it last?

10. What is residual radiation and what affects the amount produced?

645. Types of nuclear weapons/threats

1. What are the common types of nuclear bombs and how do they initiate a nuclear explosion?

2. How does a RDD differ from a RED?

3. How is the chain reaction controlled in a nuclear power plant?

4. How does an “all hazards” approach relate to a radiologic event?

646. Nuclear weapons incidents/accidents

1. What is a nuclear weapon incident?

2. What term is applied to a nuclear weapons accident?

647. Role of BE in the nuclear enterprise

1. What is it imperative that BE personnel ***not*** do at the outset of a radiological incident?

2. What are the three phases of a radiological monitoring at a nuclear device incident/accident site?

3. What is the most effective life-saving opportunity for response officials in the first hour following a nuclear incident/accident?

4. What are the four pathways victims and the responders will be exposed during a radiological incident?

5. What is the most probable means of contamination entering the body, and how can personnel be protected?

6. How long are airborne alpha activity guidelines intended for use?

7. What is the intention of anticontamination clothing?

8. What are some important factors to consider for the selection of anticontamination clothing?

9. Who is most likely to receive the highest exposure during a radiological incident, and what monitoring is done for them?

10. What is the most important factor in determining radiation exposure hazard potential?

11. What is the difference between external and internal exposure?

12. How does a chelating agent work as a medical countermeasure for RAMs?

13. When should medical treatment be delayed for contaminated patients?

14. What are the two basic types of personnel decontamination stations?

15. What should be done with contaminated waste?

16. What should be done with contaminated bodies with readings greater than 100 mrem/hr with the probe 1 inch away?

17. When do FDA DILs apply?

18. How does contamination released by a radiologic accident affect the public H_2O supply?

19. When is environmental sampling for a radiologic accident conducted?

20. When can air sampling be discontinued after a Broken Arrow?

21. Which type of nuclear plotting supersedes all others?

22. What are initial hazard assessments based on, and what are actions from them focused on?

23. Where is all data following a radiological incident/accident maintained?

Answers to Self-Test Questions

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1. Many allied and friendly countries continue to depend on the security umbrella provided by the nuclear deterrence capability of the US. In the absence of this "security umbrella" some non-nuclear allies might perceive a need to develop and deploy their own nuclear capability.
2. ICBMs, *bombers*, and SLBMs.
3. The people, organizations, processes, procedures, and systems used to conduct, execute, and support nuclear operations and forces. It includes the infrastructure and life-cycle activities for nuclear weapons, delivery platforms, and supporting systems; intellectual and technical competencies; and cultural mindset that ensure sustainable, responsive, safe, reliable, and secure AF nuclear deterrence capabilities. In addition, it includes AF organizations responsible for nuclear policy and guidance, and AF relationships with other entities who contribute to the Nation's nuclear deterrence mission.
4. Nuclear explosions can be many thousands (or millions) of times more powerful than the largest conventional detonations. Both types of weapons rely on the destructive force of the blast or shock wave.
5. It refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus. This nucleus in turn produces neutrons, and the process repeats. The process may be controlled (nuclear power) or uncontrolled (nuclear weapons).
6. Approximately 85% of the energy of a nuclear weapon produces air blast (shock) and thermal energy (heat).
7. Most damage comes from the explosive blast. The shock wave of air radiates outward, producing sudden changes in air pressure that can crush objects, and high winds that can knock objects down and send debris flying into other objects.
8. Thermal radiation damage depends very strongly on weather conditions. Clouds or smoke in the air can considerably reduce effective damage ranges versus clear air conditions.
9. Initial nuclear radiation is defined as the radiation that arrives during the first minute after an explosion and is mostly gamma and neutron radiation.
10. Fallout radiation is received from particles that are made radioactive by the effects of the explosion, and subsequently distributed at varying distances from the site of the blast. While any nuclear explosion in the atmosphere produces some fallout, the fallout is far greater if the burst is on the surface, or at least low enough for the fireball to touch the ground.

645

1. (1) Gun-type nuclear bombs use HEs to drive one sub-critical mass of enriched uranium (> 90% ^{235}U) into a stationary sub-critical mass of enriched uranium with enough force to form a critical mass.
   (2) Implosion-type bombs where the plutonium is arranged in a spherical shape (as in a core) with HEs driving the sub-critical ^{239}Pu inward using 'lenses' to focus the explosion.
   (3) The hydrogen bomb is a fission bomb, called the primary, which produces a flood of radiation including a large number of neutrons. This radiation impinges on the thermonuclear portion of the bomb, which consists largely of lithium deuteride. The neutrons react with the lithium, producing tritium and helium. In the extreme heat which exists in the bomb, the tritium fuses with the deuterium in the lithium deuteride.

   (4) The neutron bomb is a small hydrogen bomb; it differs from standard nuclear weapons insofar as its primary lethal effects come from the radiation damage caused by the neutrons it emits. It is also known as an ERW.

2. An RDD, or dirty bomb, is a conventional explosive or device, such as a dynamite package, coupled with RAM that scatters when the bomb explodes and creates a threat to public health and safety through the malicious spread of RAM. A RED, or hidden sealed source, is a terrorist device intended to expose people to significant doses of ionizing radiation without their knowledge.
3. The control rods slide up and down in between the fuel assemblies in the reactor core. They control or regulate the speed of the nuclear reaction by absorbing neutrons. When the control rods absorb neutrons, fewer neutrons hit the uranium atoms thus slowing down the chain reaction.
4. Sometimes radiation may not be the only hazard. The large number of non-radiological (secondary) weapon-specific hazards include HE materials, beryllium, lithium, lead, plastics, hydrazine, red fuming nitric acid, solid fuel rocket motors, JP fuel, and composite materials. With such a high number of potential hazards, it is imperative to recognize them and utilize an "all hazards" approach.

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1. An unexpected event involving a nuclear weapon, nuclear components, or a nuclear weapons transport, or launch vehicle when a nuclear weapon is mated, loaded, or on board that does not fall into nuclear weapons accident category. However, it involves damage to the weapon, safety and security, facility, or component resulting in any of the following, but not constituting a nuclear weapon(s) accident:
   - An increase in the possibility of, or actual occurrence of, an explosion, a nuclear detonation, or radioactive contamination.
   - Errors committed in the assembling, testing, loading, or transportation of equipment and materiel which might lead to an unintentional operation of all or part of the weapon arming or firing sequence or which could lead to a substantial change in yield or increased dud probability.
   - Loss or destruction of a nuclear weapon or radiological nuclear weapon component due to terrorist or enemy action.
   - Non-nuclear detonation or burning of a nuclear weapon or radiological nuclear weapon component.
   - Loss or destruction of a nuclear weapon or radiological nuclear weapon component, including jettisoning.
   - Public hazard, actual or implied.
   - The flagword Broken Arrow.

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1. Get involved in the dissemination of information to the public; leave this to qualified PA personnel.
2. The first phase is beta-gamma monitoring to determine if a nuclear yield has occurred, even though it is only a remote possibility. The second phase is to rapidly define the contaminated areas so they can be controlled. The last phase is continued monitoring of areas, personnel and equipment throughout decontamination and site restoration.
3. The decision to shelter populations in the expected dangerous fallout areas.
4. (1) Cloud shine, which is external gamma radiation from a plume of RAM.
   (2) Ground shine, which is external beta/gamma radiation from RAM deposited on the ground.
   (3) International radiation exposure, due to inhaling RAM, which is its primary pathway for exposure.
   (4) Skin contamination exposure, which is external beta and gamma radiation from RAM deposited on the skin and is a significant source of external skin exposure.
5. Inhalation. Satisfactory respiratory protection can be provided in most instances by using service approved protective masks.
6. The guidelines provided are intended for use until health physics personnel at the scene can develop situation-specific instructions.
7. Although it will not reduce exposure to gamma radiation, it will protect against alpha radiation and help prevent the spread of contamination.

8. Weather conditions expected at the scene, the nature and quantity of the contaminant, and the environment in which the clothing is to be worn.
9. Those least likely to have any direct personnel monitoring. These individuals are those that arrive on the scene first (e.g., passersby, homeowners, police, firemen, medics and emergency personnel involved in initial rescue and firefighting efforts).
10. The absorption of radiation in tissue is the most important factor in determining radiation exposure hazard potential.
11. External dose or exposure occurs when standing near a gamma or high-energy beta-emitting source; the external exposure stops when the person is decontaminated and leaves the area of the source. Internal dose or exposure occurs by ingesting or inhaling RAM; the internal exposure continues until the RAM is flushed from the body by natural processes or decays.
12. By binding and holding on to RAMs or poisons that get into the body. Once bound to a RAM or poison, the chelating agent is then passed from the body in the urine.
13. Necessary medical or surgical treatment must not be delayed because of possible contamination. The initial management of a casualty contaminated by radiological agents is to perform all immediate life- and limb-saving actions without regard to contamination (decontamination can always be performed later).
14. The first is a detailed decontamination station that is suitable for small affected populations and for processing response personnel into and out of the affected area. The second are decontamination stations established at community centers for large events.
15. All contaminated materials should be collected and stored in an area that is established specifically for contaminated storage, and adequate security should be provided for the area. If BE identifies the contaminated material as having short-life, the material may be held in the storage area until decontamination is accomplished by aging and then treated as nonradioactive waste. The liquid waste, such as H_2O used in decontamination of personnel and equipment cannot be released into existing sewerage facilities until it has been determined that the isotope concentration is within the limits set up in Title 10 CFR Part 20.
16. The body should be moved to a refrigeration unit at least 30 feet from the work area. This will prevent the morgue staff from exceeding their dose limits on the first few decedents and will allow the morgue staff to consult BE and devise a special work plan. If the source of the radiation is a mix of short-lived radioisotopes, it will allow radioactive decay to decrease the dose rate.
17. DILs apply during the first year after an accident. If there is concern that food will continue to be significantly contaminated beyond the first year, the long-term circumstances need to be evaluated to determine whether the DILs should be continued or if other guidance may be more applicable.
18. Contamination released by an accident should not usually affect the safety of public H_2O systems with adequate H_2O treatment capability.
19. Environmental sampling is conducted during the site remediation phase of the cleanup operation. Site remediation is the phase of accident response that addresses cleanup of contamination that may have occurred as a result of the accident and restoration of the affected area to conditions agreed upon by the stakeholders.
20. If it can be shown that RAM has not been released from a weapon, then air sampling can be discontinued. However, if a Broken Arrow has occurred, air sampling should be continued until all measurable surface contamination has been removed, and all air samples are at background level.
21. Request, receive, and use IMAAC hazard predictions. In the interim, first responders must use organic HPAC modeling tools with DTRA reach-back, or stand-alone HPAC systems for internal planning only. Use these plots until IMAAC plots are available. Once available, IMAAC plots supersede all others.
22. Initial hazard assessments shall, of necessity, be based on limited information, assumptions, and worst-case projections of possible radiation doses received. Actions in the initial response phase are focused on assessing the magnitude of the incident, establishing control zones, and facilitating the continuance of critical missions.
23. AFI 48–145 also requires data to be maintained in the approved BE management information systems, currently DOEHRS–IR for radiation.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

68. (644) Which process does nuclear fission involve?
a. Chemically bonding two atoms using helium.
b. Merging two smaller atoms into one larger atom.
c. Forcing atoms to vibrate at incredibly high speeds.
d. Splitting the nucleus of an atom into smaller fragments.

69. (644) In a hydrogen bomb, two isotopes of hydrogen, deuterium and tritium are fused to form a
a. nucleus of helium and a neutron.
b. nucleus of halon and a neutron.
c. deuterium molecule.
d. hydrogen molecule.

70. (644) What is radioactive fallout?
a. A wave of intense heat from the explosion.
b. The radiation that occurs at the time of explosion.
c. Pressure from the shock wave created by the blast.
d. Clouds of fine radioactive dust particles and debris.

71. (644) Within figure 4–7 of the text, what percentage accounts for blast effects in the overall effects of a surface nuclear detonation?
a. 5.
b. 10.
c. 35.
d. 50.

72. (644) What percentage of the energy from a nuclear explosion is made up of an intense burst of thermal radiation?
a. 5.
b. 10.
c. 35.
d. 50.

73. (644) The major incendiary effect of nuclear explosions is caused by the
a. electromagnetic pulse (EMP).
b. flash burns.
c. blast wave.
d. fireball.

74. (644) Approximately what percentage of total radioactivity does fallout contain?
a. 70.
b. 60.
c. 50.
d. 40.

75. (644) An electromagnetic pulse (EMP) from a high altitude burst
a. results in flash blindness and skin burns.
b. is a single pulse of energy that disappears in a fraction of a second.
c. will not damage most equipment designed to protect electrical facilities from lightning.
d. is an electromagnetic wave which results from secondary reactions occurring when alpha radiation is absorbed in the air or ground.

76. (645) Which type of nuclear weapon is fission-based and has a plutonium (Pu) core?
a. The neutron bomb.
b. The hydrogen bomb.
c. Gun-type nuclear bomb.
d. Implosion-type nuclear bomb.

77. (645) What is the difference between a neutron bomb and a standard nuclear weapon?
a. Physical structures are more affected by a neutron bomb.
b. There is no real discernible difference between the bombs.
c. The primary lethal effects come from the radiation damage caused by the neutrons a neutron bomb emits.
d. There is less of a distinction between areas of high lethality and areas with minimal radiation doses for neutron bombs.

78. (645) What is a radiological exposure device (RED)?
a. A regular explosive laced with lower-grade radioactive material (RAM).
b. An illicit nuclear weapon bought, stolen, or otherwise obtained that produces a nuclear explosion.
c. A device intended to expose people to significant doses of ionizing radiation (rad) without their knowledge.
d. A device in which the nuclear yield produces extreme heat, powerful shockwaves, and prompt radiation or radioactive fallout.

79. (645) Which is *not* generally considered a secondary hazard of nuclear weapons?
a. Beryllium.
b. Hydrazine.
c. Laser radiation.
d. Composite materials.

80. (645) During a non-radiological (secondary) hazard to nuclear weapons,
a. radiation has already been completely expelled.
b. the shock, heat and friction created can cause other high explosive material to detonate.
c. an initial shock wave has already occurred, leaving a thermal hazard and radiation as the only remaining issues.
d. fallout radiation penetrating protective structures will be the sole hazard after all immediate issues have been dealt with following a detonation.

81. (646) Which of the following would be categorized as a Bent Spear?
a. The forcible, unauthorized seizure of a nuclear weapon.
b. An accidental or unauthorized launch of a nuclear weapon.
c. An unfavorable environment or condition resulting in damage to the nuclear weapon.
d. A non-nuclear detonation or burning of a nuclear weapon or radiological nuclear weapon component.

82. (646) The accidental or unauthorized launching by United States (US) forces of a nuclear-capable weapon system is referred to with the flagword
a. Broken Arrow.
b. Faded Giant.
c. Bent Spear.
d. Dull Sword.

83. (647) During a military response to a radiological accident, who is the *primary* radiological health and safety advisor to the military on-scene commander (OSC)?
a. Public affairs (PA).
b. Ground safety.
c. Flight surgeon.
d. Bioenvironmental engineering (BE).

84. (647) Bioenvironmental engineering (BE) personnel have been given the task of monitoring the contamination levels on the ground in and around a Broken Arrow. Preliminary results from ambient air monitoring indicate the airborne concentration of Alpha activity is 525 disintegrations per minute per centimeters cubed (dpm/m^3) above background. As an entry team leader, what respiratory protection level should be recommended?
a. Full-face high-efficiency particulate air, absorbing, or arrestance (HEPA) respirator.
b. Self-contained breathing apparatus (SCBA).
c. No respiratory protection needed.
d. Half-face HEPA respirator.

85. (647) What types of clothing provide some protection from contamination and can be worn in lieu of special anticontamination clothing during an emergency?
a. Self-contained breathing apparatus (SCBA).
b. Civilian work clothes or military fatigues.
c. Various physical training gear.
d. Rubber gloves.

86. (647) The *primary* treatment for internal contamination is to increase the rate of elimination of the radioactive isotope. How can this be done?
a. Mechanical means.
b. Antibiotics.
c. Vaccines.
d. Water.

87. (647) Medical countermeasures that are approved to treat known or suspected internal contamination with plutonium (Pu), americium or curium are known as:
a. Chelating agents.
b. Elimination agents.
c. Chelating solutions.
d. Elimination solutions.

88. (647) When performing external decontamination of patients at the site, what should be done to ensure contamination is not spread?
a. Remove all contaminated clothing.
b. Perform treatment in the field.
c. Transport patient to hospital.
d. Closely monitor patient.

89. (647) After determining that skin contamination has occurred in a radiological incident, where should medical personnel concentrate their attention to thoroughly remove contamination?
a. Feet.
b. Arms.
c. Hands.
d. Wounds.

90. (647) To reduce the amount of radiological contamination to instruments, bioenvironmental engineering (BE) personnel can place plastic bags over radioactivity detection identification and computation (RADIAC) meters, *except* for what types of survey instrument probes?
a. Alpha.
b. Beta.
c. Gamma (**γ)**.
d. X-ray.

91. (647) When recommending contamination control procedures for deceased personnel, make sure that decontamination procedures and remains are handled
a. hastily.
b. slowly.
c. with dignity.
d. with technical prowess.

92. (647) When surveying a fatality using radiological decontamination techniques, if it is observed that the contamination cannot be removed from the body, what should be the next course of action?
a. Decontaminate again.
b. Isolate or shield the body.
c. Transport to a regular morgue.
d. Leave the deceased remains alone.

93. (647) What agency has established guidance on acceptable levels of radioactive contamination in food?
a. Environmental Protection Agency (EPA).
b. Nuclear Regulatory Commission (NRC).
c. Food and Drug Administration (FDA).
d. Department of Defense (DOD).

94. (647) What should you do if you need to conduct water sampling when responding to a short duration emergency operation?
a. Reconduct any samples that exceed acceptable radiological contamination levels.
b. Contact the United States Food and Drug Administration (FDA).
c. Consult the Air Force Radiation Assessment Team (AFRAT).
d. Inform the major command (MAJCOM).

95. (647) What step in the sampling strategy process is used to comply with regulatory requirements or to identify an associated risk to a satisfactory level?
a. Results interpretation.
b. Type of analysis.
c. Archive results.
d. Action level.

96. (647) What plotting program is widely used for initial emergency assessment or safety-analysis planning?
a. Hotspot.
b. Hazard Prediction and Assessment Capability (HPAC).
c. Interagency Modeling and Atmospheric Assessment Center (IMAAC).
d. Atmospheric Release Advisory Capability (ARAC).

97. (647) A long-term increase in the likelihood of radiation-related diseases is caused by the inhalation of what type of emitters?
a. Gamma (**γ)**.
b. Beta.
c. Alpha.
d. Tritium.

98. (647) Radiation exposure status (RES) is a system for categorizing a unit's radiation exposure level and provides guidance for protection and surveillance actions. If a person is placed in RES category R1C, what actions or tasks can they accomplish?
a. None.
b. Priority tasks only.
c. Infrastructure tasks only.
d. Life-saving mission tasks only.

99. (647) When documenting hazards encountered, protective measures taken, doses received and decontamination performed for an occupational and environmental health site assessment (OEHSA), what Air Force (AF) guidance should be referenced?
a. Air Force Instruction (AFI) 48–125, *Personnel Ionizing Radiation Dosimetry*.
b. AFI 48–145, *Occupational and Environmental Health Program*.
c. Air Force Manual (AFMAN) 48–125, *Personnel Ionizing Radiation Dosimetry*.
d. AFMAN 48–145, *Occupational and Environmental Health*.

100. (647) What Air Force guidance document requires data to be maintained in the approved bioenvironmental engineering (BE) management information system Defense Occupational and Environmental Health Readiness System-Incident Reporting (DOEHRS–IR) for radiation?
a. Air Force Manual (AFMAN) 48–145, *Occupational and Environmental Health*.
b. AFMAN 48–125, *Personnel Ionizing Radiation Dosimetry*.
c. Air Force Instruction (AFI) 48–145, *Occupational and Environmental Health Program*.
d. AFI 48–125, *Personnel Ionizing Radiation Dosimetry*.

Glossary of Abbreviations and Acronyms

°	degrees
+2	double positive
#	number
%	percent
α	alpha
β	beta
β^--	beta minus
β^+-	beta plus
γ	Gamma
λ	rate of decay
µCi	microcurie
µCi/cm^2	microcuries per centimeter squared
µg	microgram
µR/hr	microrem per hour
A	mass number
AEA	Atomic Energy Act
AF	Air Force
AFI	Air Force instruction
AFIA	Air Force Inspection Agency
AFMAN	Air Force manual
AFMSA/SG3PB	Air Force Medical Support Agency Bioenvironmental Engineering
AFPD	Air Force policy directive
AFRAT	Air Force Radiation Assessment Team
AFRRAD	Air Force Radioactive Recycle and Disposal
AFSC	Air Force specialty code
AFTTP	Air Force tactics, techniques, procedures
AL	action level
ALARA	as low as reasonably achievable
ALI	annual limits of intake
Am	americium
amu	atomic mass unit
AP	alpha probe
ARAC	Atmospheric Release Advisory Capability
ARC	Air Reserve Component
ARS	acute radiation syndrome

At	astatine
ATRAP	Air Transportable Radioactivity Detection Identification and Computation Package
ASTDR	Agency for Toxic Substances and Disease Registry
Be	beryllium
BE	bioenvironmental engineering
BEE	bioenvironmental engineer
BF_3	boron trifluoride
Bi	bismuth
BP	beta probe
Bq	becquerel
Bq/cm^2	becquerels per centimeters squared
Bq/cm^3	becquerels per centimeters cubed
Bq/kg	becquerels per kilogram
BWR	boiling water reactor
c	speed of light
C	coulomb
Ca-DTPA	calcium-diethylene triamine pentaacetic acid
CBRN	chemical, biological, radiological, and/or nuclear
C-CBRN	counter-chemical, biological, radiological, and nuclear
CDC	Centers for Disease Control and Prevention
CE	civil engineer
CEDE	committed effective dose equivalent
CF	composite fiber
CFR	Code of Federal Regulations
cGy	centigray
Ci	curie
Ci/g	curies per gram
C/kg	coulomb per kilogram
cm	centimeter
cm^2	square centimeters
CMAT	consequence management advisory team
CNS	central nervous system
CNWDI	Critical Nuclear Weapons Design Information
COA	course of action
CP	command post
cpm	counts per minute
Cs-134	Cesium–134

Cs-137	Cesium–137
cSv	centisievert
D	absorbed dose; distance
DAC	derived air concentration
DCA	dual-capable aircraft
DCF	dose conversion factor
DD	Department of Defense (pertaining to forms)
DIL	derived intervention level
DI	deionized
DNA	deoxyribonucleic acid
DHS	Department of Homeland Security
DOD	Department of Defense
DODM	Department of Defense manual
DOE	Department of Energy
DOEHRS	Defense Occupational and Environmental Health Readiness System
DOEHRS-IR	Defense Occupational and Environmental Health Readiness System-Incident Reporting
DOT	Department of Transportation
dpm	disintegrations per minute
dpm/cm^2	disintegrations per minute per centimeters squared
dpm/cm^3	disintegrations per minute per centimeters cubed
dps	disintegrations per second
DTPA	diethylene triamine pentaacetic acid
DTRA	Defense Threat Reduction Agency
DU	depleted uranium
E	equivalent energy
EC	electron capture
EDTA	ethylenediaminetetraacetic acid
EM	emergency management
EMP	electromagnetic pulse
EMT	equivalent megaton
EOC	emergency operations center
EOD	explosive ordnance disposal
EPA	Environmental Protection Agency
EPD	electronic portable dosimeter
ERW	enhanced-radiation weapon
ESOH	environmental, safety, and occupational health
eV	electron volt

F	Fahrenheit
FBI	Federal Bureau of Investigation
FDA	Food and Drug Administration
FGR	Federal Guidance Report
FGS	final governing standards
FIDLER	Field Instrument for the Detection of Low Energy Radiation
FSIS	Food Safety and Inspection Service
ft	foot; feet
ft/sec	feet per second
g	gram; mass of material (human tissue)
GI	gastrointestinal
GM	Geiger-Mueller
GWOT	Global War on Terrorism
Gy	gray
H	dose equivalent
HAF	Headquarters Air Force
He	helium
HE	high explosive
HEPA	high-efficiency particulate air, absorbing, or arrestance
HHS	Health and Human Services
H_2O	water
H_2O_2	hydrogen peroxide
Hp	personal dose equivalent
HPAC	Hazard Prediction and Assessment Capability
Hp/hr	personal dose equivalent per hour
HRA	health risk assessment
I	intensity
I-131	Iodine–131
IAW	in accordance with
IBIS	in-flight blade inspection system
IC	incident commander
ICBM	intercontinental ballistic missile
IEMP	Installation emergency management plan
IMAAC	Interagency Modeling and Atmospheric Assessment Center
IND	improvised nuclear device
IR	infrared
IRAA	Indoor Radon Abatement Act
IRSO	installation radiation safety officer

IV	intravenous
J/kg	joule per kilogram
JP	jet propulsion; joint publication
Kcpm	thousand counts per minute
keV	kiloelectron-volt
keV/µ	kiloelectron-volts per micron
kg	Kilogram
kVp	kilovolt peak
LANTIRN	low-altitude navigation and targeting infrared for night
LBDT	laboratory biological detection team
lb	pound
LCD	liquid crystal display
LD	lethal dose
LED	light emitting diode
LER	longitudinal exposure record
LET	linear energy transfer
LOC	level of concern
m	mass
mA	milliampere
MAJCOM	major command
MARSAME	Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual
MBq	megabecquerel
mCi	millicurie
MDS	meteorological data server
MERC	medical equipment repair center
METL	Mission essential task list
MeV	megaelectron-volts
mm	millimeter
MML	Master Materials License
MOPP	mission-oriented protective posture
mR	measuring exposure rates; milliroentgen
mrem	millirem
mrem/hr	millirem per hour
mR/hr	milliroentgen per hour
MSHA	Mine Safety and Health Administration
mSv	millisievert
n	neutron

Na	sodium
NARAC	National Atmospheric Release Advisory Center
NARM	naturally occurring radioactive materials or accelerator-produced radioactive materials
NARP	Nuclear Weapon Accident Response Procedures
NATO	North Atlantic Treaty Organization
nCi	nanocurie
NDI	non-destructive inspection
NEPA	National Environmental Policy Act
NIH	National Institutes of Health
NIOSH	National Institute of Occupational Safety and Health
NORM	naturally occurring radioactive material
NRC	Nuclear Regulatory Commission
NRF	National Response Framework
NUREG	nuclear regulation
OEBGD	Overseas Environmental Baseline Guidance Document
OEF	Operation ENDURING FREEDOM
OEG	operational exposure guidance
OEH	occupational and environmental health
OEHSA	occupational and environmental health site assessment
OF	occupancy factor
OIF	Operation IRAQI FREEDOM
OSC	on-scene commander
OSHA	Occupational Safety and Health Administration
OSI	office of special investigations
p	proton
PA	public affairs
PAG	protective action guide
Pb	lead
pCi	picocurie
pCi/kg	picocuries per kilogram
pCi/L	picocuries per liter
PE	positron emission
PH	public health
PMT	photomultiplier tube
Po	polonium
PPE	personal protective equipment
Pu	plutonium

PWR	pressurized water reactor
Q	quality factor
R	roentgen
R&D	research and development
R&EM	readiness and emergency management
Ra	nuclide radium
rad	one dose of ionizing radiation (1/100 of a gray)
RADeCO	Radiation Detection Company
RadDos	Radiation Dosimetry
RADIAC	Radioactivity Detection Identification and Computation
RAM	radioactive material
RAMP	Radon Assessment and Mitigation Program
RDD	radiological dispersal device
RDL	radiation dosimetry laboratory
RED	radiological exposure device
rem	roentgen equivalent man
rem/hr	roentgen equivalent man per hour
RES	radiation exposure status
R/hr	roentgen per hour
RIC	radioisotope committee
RM	risk management
Rn	radon
RNEP	Robust Nuclear Earth Penetrator
RSO	radiation safety officer
Ru	ruthenium
SA	specific activity
SAF	secretary of the Air Force
SA_i	specific activity of any isotope
SCBA	self-contained breathing apparatus
SCITEC	Science and Technology
sec	second
SecDef	secretary of defense
SG	surgeon general
SI	Systeme Internationale
SLBM	submarine-launched ballistic missile
SNCO	senior noncommissioned officer
SNM	special nuclear materials
Sr	strontium

SSAN	social security account number
STANAG	standardization agreement
Sv	sievert
$t_{1/2}$	radioisotope half-life
$T_{½}$	radioactive half-life
T_b	biological half-life
TEDE	total effective dose equivalent
T_{eff}	effective half-life
TENORM	technologically enhanced naturally occurring radioactive materials
TH	tetrahydromethylcyclopentadiene
Th-232	Thorium–232
TIC	toxic industrial chemical
TIM	toxic industrial material
TLD	thermoluminescent dosimeter
TNT	trinitrotoluene
TO	technical order
URSO	unit radiation safety officer
U-234	Uranium 234
U-235	Uranium 235
U-238	Uranium 238
UO_2	uranium dioxide
UO_3	uranium trioxide
U_3O_8	triuranium octoxide
US	United States
USAF	United States Air Force
USAFSAM	United States Air Force School of Aerospace Medicine
USDA	United States Department of Agriculture
USSTRATCOM	United States Strategic Command
V	volt
w/	with
WMD	weapons of mass destruction
W_R	radiation weighting factors
XP	X-ray probe
X-ray	radiography
Z	atomic or proton number
Zn-DTPA	Zinc-Diethylenetriamine pentaacetic acid

Student Notes

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