Teamsters
Radiological Worker
Safety & Health Training

Radiological Worker II Course

2010

Electronic Version is Section 508 Compliant

International Brotherhood of Teamsters — IBT Worker Training Program

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2010 Edition

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Table of Contents

About this Manual

This manual contains the complete text of DOE's *Radiological Worker Training Study Guides.*

Text written by the Teamsters has a double line on the side, or double lines on the top and bottom. All illustrations in this manual were added by the Teamsters.

This manual was prepared by the Radiological Worker Training Program of the International Brotherhood of Teamsters for use in **Radiological Worker I** and **Radiological Worker II** courses to prepare employees for work in radiologically controlled areas of facilities operated by the United States Department of Energy (DOE).

DOE Directive N 441.1 (extended by N 441.2) states:

(6)(c)(1) Radiation safety training for ... radiological workers ... shall utilize those portions of the standardized core training materials published by DOE that are relevant to facility hazards and operations, augmented as necessary by site-specific materials Documentation of satisfactory completion of the entire DOE standardized core course(s) shall be accepted by all DOE activities.

(6)(c)(2) Training requirements commensurate with the hazard within a posted area shall be completed prior to permitting an individual unescorted access to that area.

In compliance with the directive, this manual contains all of the standardized core training materials, and covers all of the enabling objectives published in Radiological Worker Training Study Guides, DOE/ EH¬0261T-2, May 1995. The material in this manual will be augmented by appropriate site-specific materials.

In addition to the text of Radiological Worker Training Study Guides, this manual contains text and illustrations written by the Teamsters to enhance each student's understanding. Text added by the Teamsters has a double line along the side, like the section you are now reading, or has a double line on the top and bottom, like the note at the right. Text which does not have a double line on the side, or on the top and bottom, comes directly from Radiological Worker Training Study Guides. All illustrations were added by the Teamsters.

This manual was prepared under a grant from the National Institute of Environmental Health Sciences (NIEHS Grant Number 5 U45 ES09760-10).

About Teamster Training Programs

In addition **to Radiological Worker Training,** the Teamsters offer courses that meet federal and state requirements for **hazardous waste workers** and **hazmat transportation workers**. Teamster training is provided by certified, experienced instructors using effective adult education methods, real equipment, and realistic hands-on activities.

All Teamster Training Centers are equipped with mobile units that can travel to local union halls, construction and remediation sites, government facilities or other locations to train workers. For more information, or to schedule a course, contact the Teamster NIEHS Worker Training Grants Office at:

IBT NIEHS Worker Training Grants Office 25 Louisiana Avenue, N.W.
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About the Teamster

The International Brotherhood of Teamsters was founded in 1903. We now represent 1.4 million workers in the construction industry, transportation, and in almost every other type of employment.

In 1973, the Teamsters established a Safety and Health epartment. It was one of the first unions to do so. The Safety and Health Staff includes professionals in safety, industrial hygiene and adult education. You can reach the Teamsters Safety and Health Department at:

IBT Safety and Health Department 25 Louisiana Avenue, N.W.
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Course Objective

Upon completion of this training course, the participant will have the knowledge to work safely in areas controlled for radiological purposes using proper radiological practices.

DOE Safety Policy

The Department of Energy, in conjunction with each site, is firmly committed to having a radiological control program of the highest quality. This program, as outlined in the DOE Radiological Control Manual (RCM), requires that managers and supervisors at all levels be involved in the planning, scheduling and conduct of radiological work. This directive also requires that adequate radiological safety shall not be compromised to achieve production or research objectives.

Course Overview

There are four areas of training that will qualify a person to be a radiological worker. These areas of training include:

Core Academics: This lesson plan includes seven (7) units which discuss the theory that a worker must know to work safely around radiological hazards.

High Radiation/Very High Radiation Area (HR/VHR): This lesson plan discusses proper entry and exit requirements into HR/VHR areas where contamination is not a concern.

Contamination Control: This lesson plan discusses proper entry and exit requirements into contaminated areas.

Course Overview (Continued)

Practical Factors Evaluation: This evaluation is a generic practical exercise that provides a hands-on experience for the worker. The practical factors exercises are different for Radiological Worker I and Radiological Worker II.

Radiological Worker I (RW I) Training consists of the Core Academics plus the practical factors evaluation. This training is required for radiological workers whose job assignments require access to Radiological Buffer Areas and Radiation Areas. RW I training is also required for unescorted entry into Radioactive Material Areas containing either sealed radioactive sources or radioactive material labeled and packaged in accordance with Articles 412 and 413 of the DOE RCM.

RW I training alone does not prepare the worker to work around higher radiation levels or with contaminated materials. It is suggested that RW I tasks be limited to inspections, tours and activities that involve work on non radiological systems.

The HR/VHR Area lesson plan may be added to the RW I course to give personnel unescorted entry into High and Very High Radiation Areas where contamination is not a concern.

Radiological Worker II (RW II) Training consists of the Core Academics, HR VHR Area lesson plan, Contamination Control lesson plan and the Practical Factors evaluation. This training is required for the radiological worker whose job assignments involve unescorted entry into High and Very High Radiation Areas, Contamination Areas, High Contamination Areas and Airborne Radioactivity Areas. Further, workers who have potential contact with hot particles or the use of glove boxes with high contamination levels shall complete RW II training.

RWI training by itself does not allow a worker to work in contaminated areas or in high and very high radiation areas.

RWII training is required for work in high and very high radiation areas, contamination areas, high contamination areas, and airborne radioactivity areas.

Course Overview (Continued)

RW II training prepares the worker to work around higher radiation levels and with contaminated materials normally associated with radiological facilities/ activities.

Evaluation Criteria: At the completion of the course the participant must successfully complete a written exam and a practical evaluation to be trained as a radiological worker. Successful completion of the written exam is a prerequisite for the practical factors evaluation.

The student must score at least 80% on both the written final exam and the practical factors evaluation.

Successful completion of the written examination (minimum score of 80%) must be achieved. The written exam is based on the objectives in the theory portion of the course.

Successful completion of the practical factors evaluation (minimum score of 80%) must be achieved. The practical factors evaluation includes entry into a simulated controlled work environment. This evaluation is based on the application of the theory portions of this course.

Use of Exercises: The use of the exercises at the end of each module in this study guide is optional. The purpose of the exercises are to help the student prepare for the written examination.

The instructor may assign other exercises or study assignments which the student is required to complete.

For More Information

For more information, or to schedule a course, contact:

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- notes -

Chapter

1

Radiological Fundamentals

Learning Objectives

Upon completion of this unit the participant will be able to IDENTIFY the fundamentals of radiation, radioactive material and radioactive contamination.

The participant will be able to SELECT the correct response from a group of responses which verifies his/her ability to:

EO 1. IDENTIFY the three basic particles of an atom and the charge and location of each.
EO 2. DEFINE ionization.

EO 3. DEFINE ionizing radiation, radioactive material and radioactive contamination.
EO 4. DISTINGUISH between ionizing radiation and non-ionizing radiation.
EO 5. DEFINE radioactivity and radioactive half-life.
EO 6. STATE the four basic types of ionizing radiation.
EO 7. IDENTIFY the following for each of the four types of ionizing radiation:

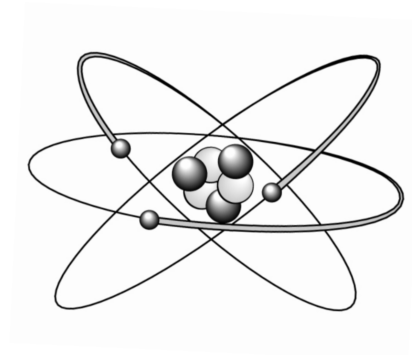
a. Physical characteristics.
b. Range and shielding.
c. Biological hazard(s).
d. Sources.

EO 8. IDENTIFY the units used to measure radiation, contamination and radioactivity.
EO 9. CONVERT rem to millirem and millirem to rem.

The DOE calls these "Enabling Objectives". Hence the designations, EO 1, EO 2, etc.

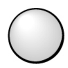
Atomic Structure

The basic unit of matter is the atom. The three basic particles of the atom are protons, neutrons, and electrons. The central portion of the atom is the nucleus. The nucleus consists of protons and neutrons. Electrons orbit the nucleus similar to the way planets orbit our sun.



Protons 

- Located in the nucleus of the atom.
- Positive electrical charge.
- Number of protons determines the element.



Neutrons

- Located in the nucleus of the atom.
- No electrical charge.
- Atoms of the same element have the same number of protons, but can have a different number of neutrons.
- Atoms which have the same number of protons but a different number of neutrons are called isotopes.
- Isotopes have the same chemical properties; however, the nuclear properties can be different.

Electrons 

- Orbit the nucleus.
- Negative electrical charge.
- Determine the chemical properties of an atom.

The outer electrons on one atom can "stick" to the outer electrons on another atom, creating a chemical bond. This is how chemical compounds are formed from two or more atoms. This is why the electrons determine the chemical properties of an atom.

electron

- One of the 3 basic particles in the atom.
- Located in orbit in the electron cloud.
- Electrical charge of minus one (-1).
- Weighs about 2000 times less than a proton or neutron.

proton

- One of the 3 basic particles in the atom.
- Located in nucleus.
- Electrical charge of plus one (+1).
- Weighs a tiny bit less than a neutron, and about 2000 times more than an electron.

neutron

- One of the 3 basic particles in the atom.
- Located in nucleus.
- No electrical charge.
- Weighs a tiny bit more than a proton, and about 2000 times more than an electron.

Atoms and Chemistry

There are ninety-two naturally occurring elements: ninety-two kinds of atoms. Each of the thousands of different chemicals in the universe is made of some combination of one or more of these ninety-two elements.

Atoms combine to form molecules. Some molecules have only two atoms. Others can have many more. An example of a molecule which has thousands of atoms is DNA, the molecule that makes up the genetic material in our cells.

Atoms combine to form molecules because the outermost electrons of one atom interact with the outer electrons of another atom. In some cases the atoms share their outer electrons, forming one electron cloud that surrounds them all. In other cases, one atom donates its outer electron(s) to another atom, creating two ions that are held together by electric attraction. All Chemical reactions depend on the interactions between the electrons of two or more atoms.

Ionizing radiation comes from the nucleuses of atoms. When it reaches another atom it can remove an electron from that atom. The removal of an electron (ionization) can affect how the atom reacts chemically. An atom which has lost an electron (an ion) may be more likely to react with other atoms than an atom which has not been ionized.

An ionized atom may be more likely to undergo chemical reactions because it is trying to replace its missing electron. It may be able to do this by sharing or borrowing an electron from another atom when it combines with that atom to form a chemical compound.

If atoms in an important chemical in our body, such as our DNA, are ionized, those atoms might react with other atoms to form a slightly different DNA. DNA provides the information which tells our cells how to function normally. If the DNA is altered, then the cell might get the wrong information.

We will discuss the way in which ionization can damage cells in Chapter 2.

Stable And Unstable Atoms

Only certain combinations of neutrons and protons result in stable atoms.

- If there are too many or too few neutrons for a given number of protons, the resulting nucleus will have too much energy. This atom will not be stable.

- The unstable atom will try to become stable. It does this by giving off excess energy in the form of particles or waves (radiation). These unstable atoms are also known as radioactive atoms.

Charge Of The Atom

The number of electrons and protons determines the overall electrical charge of the atom. The term ion is used to define atoms or groups of atoms that have a net positive or negative electrical charge.

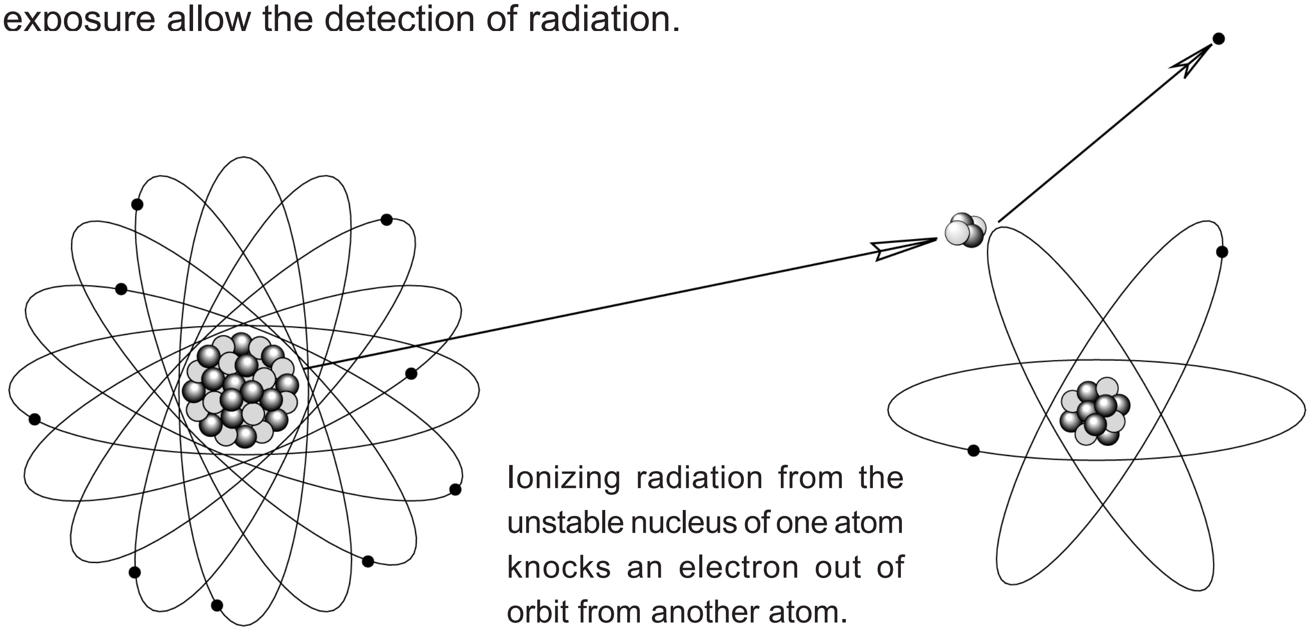
- No charge (neutral) - If the number of electrons equals the number of protons, the atom is electrically neutral and has no net electrical charge.

- Positive charge (+) - More protons than electrons.

- Negative charge (-) - More electrons than protons.

Important Definitions

Ionization: Ionization is the process of removing electrons from neutral atoms. Electrons will be removed from neutral atoms if enough energy is supplied. The remaining atom has a positive (+) charge. The positively charged atom and the negatively charged electron are called an ion pair. Ionization should not be confused with radiation. Ions (or ion pairs) produced as a result of radiation exposure allow the detection of radiation.



Ionizing radiation from the unstable nucleus of one atom knocks an electron out of orbit from another atom.

Ionizing radiation: Energy (particles or rays) emitted from radioactive atoms that can cause ionization. The four basic types of ionizing radiation that are of primary concern in the nuclear industry are alpha particles, beta particles, gamma or x rays, and neutron particles.

Non-ionizing radiation: Radiation that doesn't have enough energy to ionize an atom. Examples of non-ionizing radiation are radar waves, microwaves and visible light.

Definitions (Continued)

Radioactivity: Radioactivity is the process of unstable (or radioactive) atoms trying to become stable. This is done by emitting radiation.

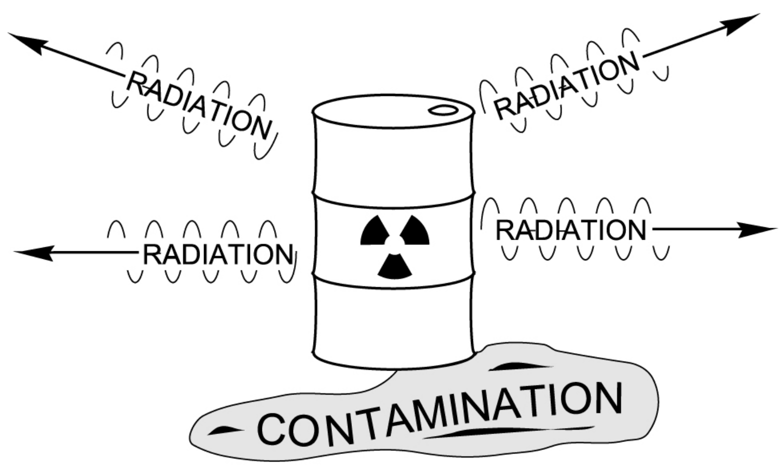
Radioactive material: Any material containing (unstable) radioactive atoms that emit radiation.

Radioactive contamination: Radioactive contamination is radioactive material in an unwanted place. (There are certain places where radioactive material is beneficial).

Exposure to radiation does not result in contamination of the worker. Radiation is a type of **energy** and **contamination** is material in an unwanted place.

Radiation is a form of energy.

Contamination is a material.



Radioactive decay: Radioactive decay is the process of radioactive atoms releasing radiation over a period of time. This is done to try and become stable (non-radioactive). Radioactive decay is also known as disintegration.

Radioactive half-life: Radioactive half-life is the time it takes for one half of the radioactive atoms present to decay.

Four Basic Types Of Ionizing Radiation

There are four basic types of ionizing radiation:

- Alpha particles
- Beta particles
- Gamma rays (or x-rays)
- Neutron particle

Alpha Particles

Physical characteristics: The alpha particle (α) has a large mass and consists of two protons, two neutrons and no electrons. It is a charged particle (charge of plus two) that is emitted from the nucleus of an atom. The positive charge causes the alpha particle to strip electrons from nearby atoms as it passes through the material, thus ionizing these atoms.

Range: The alpha particle deposits a large amount of energy in a short distance of travel. This large energy deposit limits the penetrating ability of the alpha particle to a very short distance. This range in air is about one to two inches.

Shielding: Alpha particles are stopped by a few inches of air, a sheet of paper, or the dead outer layer of skin.

Biological hazard: Alpha particles do not present an external hazard because they are easily stopped by the dead layer of skin on your body. Internally, the source of the alpha radiation is in close contact with body tissue and can deposit large amounts of energy in a small volume of body tissue.

List the alpha sources at your site:

____

____

____

Beta Particles

Physical characteristics: The beta particle (β) has a small mass and is usually negatively charged. It is emitted from the nucleus of an atom and has an electrical charge of minus one. Beta radiation causes ionization by displacing electrons from their orbits. Ionization occurs due to the repulsive force between the beta particle and the electron, which both have a charge of minus one.

A negatively charged beta particle has the same charge and mass as an electron. It is sometimes referred to as a very fast moving electron. However, it is emitted from the nucleus. It does not come from the electrons that orbit the atom.

Range: Because of its charge, the beta particle can only penetrate a short distance - Range in air is about 10 feet.

Shielding: Most beta particles can be shielded by plastic, glass, metal foil, or safety glasses.

Biological hazard: If ingested or inhaled, the source of the beta radiation is in close contact with body tissue and can deposit energy in a small volume of body tissue. Externally, beta particles are potentially hazardous to the skin and eyes.

List the beta sources at your site:

____
____
____
____

Gamma Rays and X Rays

Physical characteristics: Gamma radiation (γ) is an electromagnetic wave or photon and has no electrical charge. Gamma rays are very similar to x rays. The main difference between gamma rays and x rays is that gamma rays originate inside the nucleus and x rays originate outside the nucleus. Gamma radiation and x ray radiation can ionize an atom by directly interacting with the electron.

Range: Because gamma and x ray radiation have no charge and no mass, they have a very high penetrating ability. The range in air is very far. It will easily go several hundred feet.

Shielding: Gamma and x ray radiation are best shielded by very dense materials, such as concrete, lead or steel.

Biological hazard: Because gamma and x ray radiation has the ability to penetrate through the body, they are considered a whole body hazard.

List the gamma and x ray sources at your site:

____

____

____

____

Neutron Particles

Physical characteristics: Neutron radiation (N) consists of neutrons that are ejected from the nucleus. A neutron has no electrical charge.

A direct interaction occurs as the result of a collision between a neutron and a nucleus.

A charged particle or other ionizing radiation may be emitted during this direct interaction. The emitted radiation can cause ionization in human cells. This is called “indirect ionization”.

Range: Because of the lack of a charge, neutrons have a relatively high penetrating ability and are difficult to stop. The range in air is very far. Like gamma rays, they can easily travel several hundred feet in air.

Shielding: Neutron radiation is best shielded by materials with a high hydrogen content, such as water, concrete, or plastic.

Biological hazard: Because neutrons have the ability to penetrate through the body, they are considered a whole body hazard.

List the neutron sources at your site:

____

____

____

____

Ionizing Radiation				
	Alpha (α)	**Beta** (β)	**Gamma** (γ)	**Neutron (N)**
Range in Air	Two inches	About 10 feet	Long range	Long range
Penetrating Ability	Low	Medium	High	High
Shielding	Paper, outer layer of skin	Wood, plastic, aluminum, safety glasses	Lead, steel, concrete, soil, water	Water, plastic,
Biological Hazard	Internal hazard only	Internal and skin and eyes	Internal and external hazard	Internal and external hazard

Radioactive Half-Life

Suppose that you have a certain quantity of uranium. Each uranium nucleus is unstable, but they don't all decay at once. There is a certain probability that a nucleus will decay. If this probability is low, then only a few of the nucleuses will decay at a time, and it will take a long time for one-half of the nucleuses to decay. The time that it takes for one-half of the nucleuses to decay is called the **radioactive half-life.**

After one half-life, one-half of the original atoms have decayed. After a second half-life, one-half of the remaining atoms decay, and so on. Different radioactive isotopes have different half lives, ranging from a few seconds to tens of thousands of years.

If you start with 1 pound of a radioactive element, after one half-life, you will have ½ pound of the element; after two half-lives, ¼ pound, and so on.

Radioactive Decay Series

When a radioactive nucleus gives off radiation, the atom becomes a different element.

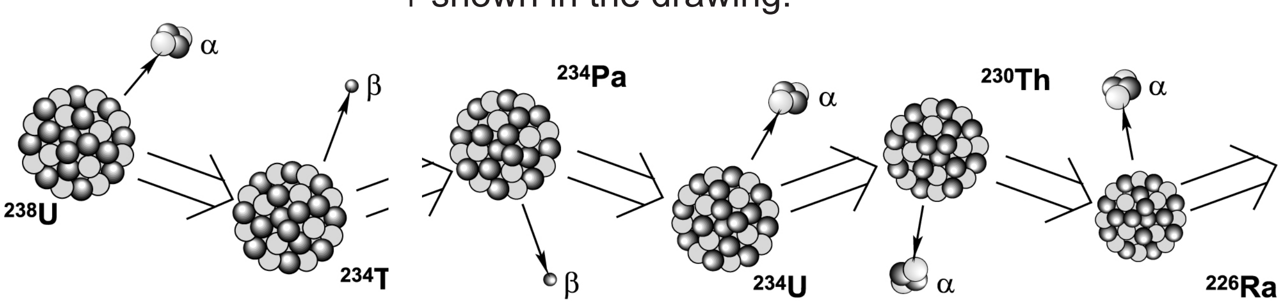
For example, uranium 238 has 92 protons. When it gives off an alpha particle it loses two protons and two neutrons. Since the number of protons is what makes an atom be the element that it is, the uranium atom has become thorium 234, which has 90 protons. When an atom gives off an alpha, it becomes the element which has two less protons than the original atom.

When an atom gives off a beta particle, one of the neutrons changes to a proton. This means that the atom becomes the element which has one more proton than the original atom. Remember that a neutron is a tiny bit bigger than a proton. The difference is about the same as the size of an electron or a beta. You might think of a neutron as a combination of a proton and a beta. These have different charges, so they cancel out, leaving no charge. If you take the beta away, then a positively charged proton remains.

If the new atom that forms after alpha or beta emission is not stable, then it too will also give of radiation, and become another element. This process, called a radioactive decay series, continues until a stable atom is formed. The **radioactive decay series** which begins with uranium 238 is listed in the box at the left. The first six steps in the series are shown in the drawing:

^{238}U Decay Series

Uranium 238 $\rightarrow\alpha$
Thorium 234 $\rightarrow\beta$
Protactinium 234 $\rightarrow\beta$
Uranium 234 $\rightarrow\alpha$
Thorium 230 $\rightarrow\alpha$
Radium 226 $\rightarrow\alpha$
Radon 222 $\rightarrow\alpha$
Polonium 218 $\rightarrow\alpha$
Lead 214 $\rightarrow\beta$
Bismuth 214 $\rightarrow\beta$
Polonium 214 $\rightarrow\alpha$
Lead 210 $\rightarrow\beta$
Bismuth 210 $\rightarrow\beta$
Polonium 210 $\rightarrow\alpha$
Lead 206 (stable)



Units Of Measure

There are several units for measuring radiation. Which one we use depends on what property of the radiation we want to measure.

This is like the way we use different units in other measurements. For example, to measure the length of a dump truck, we use feet. To measure its capacity, we use cubic yards. To measure how fast it goes, we use miles per hour. These all measure the same truck, but we use different units for different properties of the truck (length, capacity, speed, etc.).

There are several properties of radiation that we might measure: the energy of the radiation as it moves through the air, the amount of energy deposited in biological tissue, the effect of the radiation in tissue, the rate at which the energy is being deposited, the rate at which a radioactive material is disintegrating, etc.

Radiaiton Energy In Air (Roentgens)

The **Roentgen** is a unit for measuring radiation exposure. It is defined only for the effect on air. It applies only to gamma and x rays. It does not relate biological effects of radiation to the human body.

1 R (Roentgen) = 1000 milliroentgen (mR)

Here we are talking about radiation as it moves through the air. We are not talking about airborne radioactivity.

Energy Absorbed From Radiation (Rads)

The **rad** is a unit for measuring absorbed dose in any material. Absorbed dose results from energy being deposited by the radiation. It is defined for any material. It applies to all types of radiation. It does not take into account the potential effect that different types of radiation have on the body.

1 rad = 1000 millirad (mrad)

Dose Equivalence of Radiation (Rems)

The **rem** is a unit for measuring dose equivalence. It is the most commonly used unit and pertains to the human body. The rem takes into account the energy absorbed (dose) and the biological effect on the body due to the different types of radiation. "Rem" stands for "Roentgen equivalent man."

1 rem = 1000 millirem (mrem)

Quality Factor

Some types of ionizing radiation do more damage to cells than other types. For example, one rad of alpha has twenty times the biological effect of one rad of gamma. The **quality factor** is a number that indicates how many times more biological effect the radiation has, as compared to gamma radiation. The quality factors are listed in the box at the side. To get from rads to rems, multiply by the proper quality factor:

Dose Equivalent (rems) = Dose (rads) x Quality Factor

For example, 0.3 rad of alpha radiation has a biological effect (dose equivalent) of 6 rem:

0.3 rad x 20 = 6 rem

Quality Factors

Gamma	1
Beta	1
Neutron	3-11
Alpha	20

Dose And Dose Rate (mrem/hour)

Dose is the amount of radiation you receive. Radiation dose rate is the rate at which you receive the dose.

Examples:

- Radiation dose rate = dose/time

- Radiation dose rate = mrem/hr

Radioactivity and Radioactive Contamination

Radioactivity is measured in the number of disintegrations radioactive material undergoes in a certain period of time.

- Disintegrations per minute (dpm)

- Counts per minute (cpm)

- Curie (Ci)

- 1 Ci = 2,200,000,000,000 (2.2 x 1012) disintegrations per minute (dpm)

- 1 Ci = 37,000,000,000 (3.7 x 1010) disintegrations per second (dps)

- For the radioactivity in air and water the curie (Ci) or microcurie (μCi) is most often used.

- 1 curie = 1,000,000 mCi

Contamination is radioactivity measured per unit area or volume. For example, cpm/cm2.

The Periodic Table of the Elements

Key: 1 — Atomic Number; H — Chemical Symbol; 1 — Atomic Weight; Hydrogen — Chemical Name

1 H 1 Hydrogen																	2 He 4 Helium
3 Li 7 Lithium	4 Be 9 Berrylium											5 B 11 Boron	6 C 12 Carbon	7 N 14 Nitrogen	8 O 16 Oxygen	9 F 19 Fluorine	10 Ne 20 Neon
11 Na 23 Sodium	12 Mg 24 Magnesium											13 Al 27 Aluminum	14 Si 26 Silicon	15 P 31 Phosphorus	16 S 32 Sulfur	17 Cl 35.5 Chlorine	18 Ar 40 Argon
19 K 39 Potassium	20 Ca 40 Calcium	21 Sc 45 Scandium	22 Ti 48 Titanium	23 V 51 Vanadium	24 Cr 52 Chrome	25 Mn 56 Manganese	26 Fe 56 Iron	27 Co 56 Cobalt	28 Ni 59 Nickel	29 Cu 70 Copper	30 Zn 65 Zinc	31 Ga 70 Gallium	32 Ge 73 Germanium	33 As 76 Arsenic	34 Se 79 Selenium	35 Br 80 Bromine	36 Kr 84 Krypton
37 Rb 85 Rubidium	38 Sr 88 Strontium	39 Y 89 Yttrium	40 Zr 91 Zirconium	41 Nb 93 Niobium	42 Mo 95 Molybdenum	43 Tc 99 Technetium	44 Ru 101 Rhythenium	45 Rh 103 Rhodium	46 Pd 106 Paladium	47 Ag 108 Silver	48 Cd 112 Cadmium	49 In 115 Indium	50 Sn 119 Tin	51 Sb 122 Antimony	52 Te 128 Telurium	53 I 127 Iodine	54 Xe 131 Xenon
55 Cs 133 Cesium	56 Ba 137 Barium	57 La 139 Lanthanum	72 Hf 179 Halfnium	73 Ta 181 Tantalum	74 W 184 Tungsten	75 Re 186 Rhenium	76 Os 190 Osmium	77 Ir 192 Iridium	78 Pt 195 Platinum	79 Au 204 Gold	80 Hg 201 Mercury	81 Tl 204 Thalium	82 Pb 207 Lead	83 Bi 209 Bismuth	84 Po 210 Polonium	85 At 210 Astatine	86 Rn 222 Radon
87 Fr 223 Francium	88 Ra 226 Radium	89 Ac 227 Actinium															

58 Ce 140 Cerium	59 Pr 141 Praseodymium	60 Nd 144 Neodymium	61 Pm 147 Promethium	62 Sm 150 Samarium	63 Eu 152 Europium	64 Gd 157 Gedolinium	65 Tb 159 Terbium	66 Dy 163 Dysprosium	67 Ho 165 Hokminium	68 Er 167 Erbium	69 Tm 169 Thulium	70 Yb 173 Ytterbium	71 Lu 175 Lutetium
90 Th 232 Thorium	91 Pa 231 Protactinium	92 U 238 Uranium	93 Np 237 Neptunium	94 Pu 242 Plutonium	95 Am 243 Americium	96 Cm 247 Curium	97 Bk 247 Berkelium	98 Cf 251 Californium	99 Es 254 Einsteinium	100 Fm 253 Fermium	101 Md 256 Mendelevium	102 No 254 Nobelium	103 Lr 257 Lawrencium

Exercises

1. The three basic parts of an atom are the:
a. ________________________________
b. ________________________________
c. ________________________________

2. State the charge of the particles and their location within the atom:

Particle	Location	Charge
a. Electron	_____________	_________
b. Neutron	_____________	_________
c. Proton	_____________	_________

3. Ionization is the process of ____________________ electrons from ______________. Electrons will be removed if enough ________________ is supplied.

4. The four basic types of ionizing radiation are

a. _______________ particles.
b. _______________ particles.
c. _______________ particles.
d. _______________ or_______________ rays.

5. Radioactive _______________ is radioactive material in an unwanted place.

6. _______________ radiation doesn't have enough energy to _______________ an atom.

7. _______________ is the process of radioactive atoms becoming stable by emitting _______________.

8. Radioactive ___________-___________ is the time it takes for one half of the radioactive atoms present to decay.

Exercises (Continued)

9. The units used to measure radiation are:
   a. ____________________ (radiation exposure)
   b. ____________________ (radiation dose)
   c. ____________________ (radiation dose equivalent)

10. The units used to measure contamination or radioactivity are
    a. _____________________________ per minute
    b. _____________________________ per minute
    c. _____________________________

11. Complete the following conversions.

a. 1000 mrem = _____________ rem

b. 350 mrem = _____________ rem

c. 2500 mrad = _____________ rad

d. 0.50 rem = _____________ mrem

e. 1.25 rem = _____________ mrem

12. Fill in the following table:

Type of Radiation	**Alpha**	**Beta**	**Gamma or X Ray**	**Neutron**
Mass				
Charge				
Range in Air				
Shielding				
Hazard				

Chapter

2

Biological Effects of Radiation

Learning Objectives

Upon completion of this unit, the participant will be able to DISCUSS the biological risks to the exposed population.

The participant will be able to SELECT the correct response from a group of responses which verifies his/her ability to:

EO 1. IDENTIFY the average annual dose to the general population from natural background and man-made sources of radiation.

EO 2. IDENTIFY the major sources of natural background and man-made radiation.

EO 3. STATE the method by which radiation causes damage to cells.

EO 4. IDENTIFY the possible effects of radiation on cells.

EO 5. DEFINE the terms “acute dose” and “chronic dose.”

EO 6. STATE examples of a chronic radiation dose.

EO 7. DEFINE the terms “somatic effect” and “heritable effect.”

EO 8. STATE the potential effects associated with prenatal radiation dose.

EO 9. COMPARE the biological risks from chronic radiation doses to health risks workers are subjected to in industry and daily life.

Introduction To This Chapter

Of all the environmental factors that can affect our health, we know more about the biological effects of ionizing radiation than any other. Rather than just being able to base our information on animal studies, we also have a large body of information available regarding exposures to humans.

There are 4 major groups of people that have been exposed to significant levels of radiation.

- The first is some early workers, such as radiologists, who received large doses of radiation before the biological effects were recognized. Since that time standards have been developed to protect workers.

How we know what we know about the health effects of radiation:

1. **Early rad workers.**
2. **Atomic bomb victims.**
3. **Rad accident victims.**
4. **Cancer patients.**

- The second group is the more than 100,000 survivors of the atomic bombs dropped at Hiroshima and Nagasaki. These survivors received estimated doses in excess of 50,000 mrem.

- The third group is individuals who have been involved in radiation accidents, the most notable being the Chernobyl accident.

- The fourth and largest group of individuals are patients who have undergone radiation therapy for cancer.

Sources Of Radiation

We live in a radioactive world and we always have. In fact, the majority of us will be exposed to more ionizing radiation from natural background radiation than from our jobs.

Natural Sources

As human beings, we have evolved in the presence of ionizing radiation from naturally occurring sources. There are several sources of radiation that occur naturally. The radiation emitted from these sources is identical to the radiation that results from man-made sources. The four major sources of naturally occurring radiation exposures are:

1. **Cosmic radiation.**

2. **Sources in the earth's crust (terrestrial radiation).**

3. **Sources in the human body (internal sources).**

4. **Radon gas in the atmosphere.**

Cosmic Radiation

Cosmic radiation comes from the sun and outer space. It consists of positively charged particles, as well as gamma radiation. At sea level, the average annual cosmic radiation dose is about 26 mrem. At higher elevations, the amount of atmospheric shielding decreases and thus the dose increases. The total average annual dose to the general population from cosmic radiation is about 28 mrem.

Terrestrial Radiation

There are natural sources of radiation in the ground (rocks, building materials and drinking water supplies). Some of the contributors to terrestrial sources are the natural radioactive elements radium, uranium and thorium. Many areas have elevated levels of terrestrial radiation due to increased concentrations of uranium or thorium in the soil. The total average annual dose to the general population from terrestrial radiation is 28 mrem.

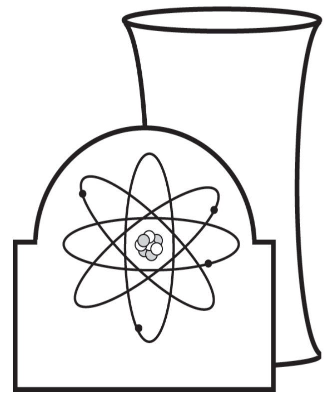
Internal Sources

The food we eat and the water we drink all contain some trace amounts of natural radioactive materials. These naturally occurring radioactive materials deposit in our bodies and, as a result, cause an internal exposure to radiation. Some naturally occurring radioactive isotopes include Sodium-24, Carbon-14, Argon-41 and Potassium-40. Most of our internal exposure comes from Potassium-40. Combined exposure from internal sources of natural background radiation account for a radiation dose of about 40 mrem per year.

Radon Gas

Radon comes from the radioactive decay of radium, which is naturally present in the soil. Because radon is a gas, it can travel through the soil and collect in basements or other areas of a home. Radon emits alpha radiation. Because alpha radiation cannot penetrate the dead layer of skin on your body, it presents a hazard only if taken in to the body. Radon and its decay products are present in the air, and when inhaled can cause a dose to the lungs. The average annual dose equivalent from radon gas is approximately 200 mrem.

Man-made Sources



The difference between man-made sources of radiation and naturally occurring sources is the place from which the radiation originates.

The four major sources of man-made radiation exposures are:

1. Medical radiation.

2. Atmospheric testing of nuclear weapons.

3. Consumer products.

4. Industrial uses.

Medical Radiation Sources include **x-rays** and radioactive sources used for **diagnosis and therapy**.

X rays are similar to gamma rays. However, they originate outside the nucleus. X rays are an ionizing radiation hazard. A typical radiation dose from a chest x ray is about 10 mrem. The total average annual dose to the general population from medical x rays is 40 mrem.

In addition to x rays, radioactive sources are used in medicine for **diagnosis and therapy**. The total average annual dose to the general population from these sources is 14 mrem.

Atmospheric Testing of Nuclear Weapons. Another man-made source of radiation includes residual fallout from atmospheric nuclear weapons testing in the 1950's and early 1960's. Atmospheric testing is now banned by most nations. The average annual dose from residual fallout is less than one mrem.

Man-made Sources (continued)

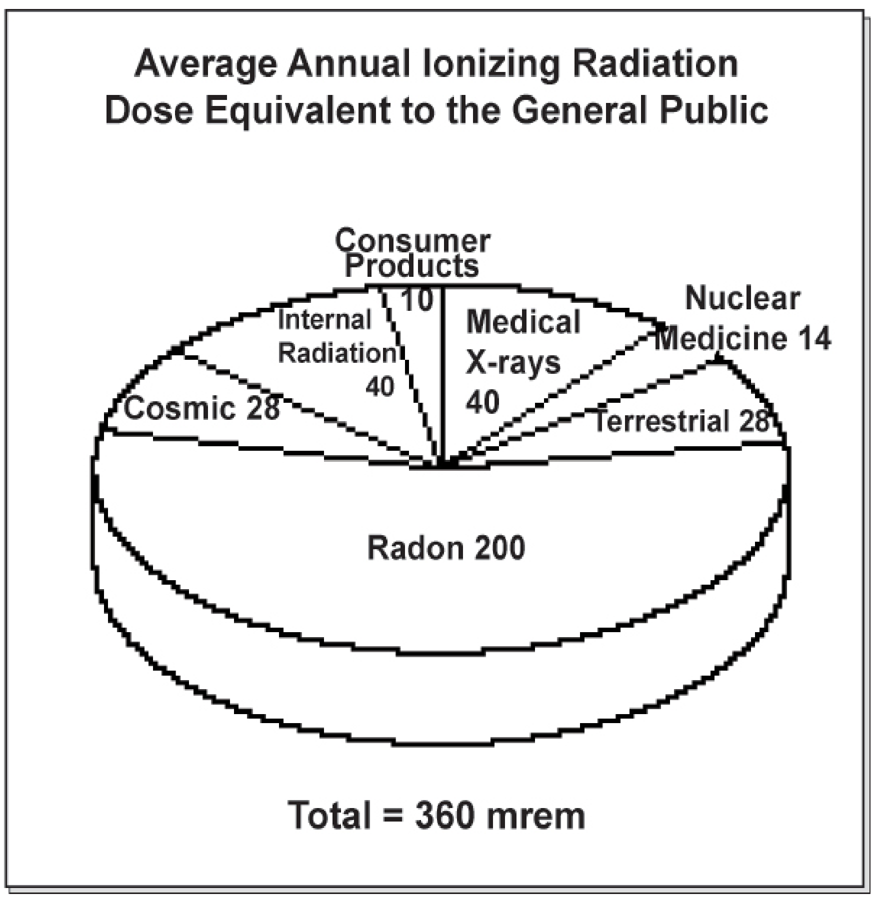
Consumer products. Examples include televisions, older luminous dial watches, and smoke detectors that contain americium (the most common kind). This dose is relatively small as compared to naturally occurring sources of radiation and averages 10 mrem in a year.

Industrial uses of radiation. These include x-ray machines used for baggage inspection, video display terminals, and tungsten welding rods.

The Average: 360 mrem

The average annual ionizing radiation dose equivalent to the general population from naturally occurring and man-made sources is **360 millirem.**

These figures represent the average exposure to the population as a whole. Your personal dose equivalent is the sum of the different doses that you actually receive. For example, if you have no medical x-rays, then your dose from x-rays is zero. If you receive radiation therapy, your nuclear medicine dose might be thousands of mrem. If you live at a high altitude, your cosmic dose will be greater than the average given here.



Effects Of Radiation On Cells

The human body is made up of many organs, and each organ of the body is made up of specialized cells. Ionizing radiation can potentially affect the normal operation of these cells.

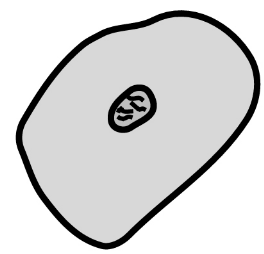
Biological effects begin with the ionization of atoms.

- The method by which radiation causes damage to human cells is by ionization of atoms in the cells. Atoms make up cells that make up the tissues of the body. These tissues make up the organs of which our body consists. Any potential radiation damage to our body begins with damage to atoms.

- A cell is made up of two principal parts, the body of the cell and the nucleus, which is like the brain of the cell.

- When ionizing radiation hits a cell, it may strike a vital part of the cell like the nucleus or a less vital part of the cell, like the cytoplasm.

Biological effects begin with the ionization of atoms in living cells.

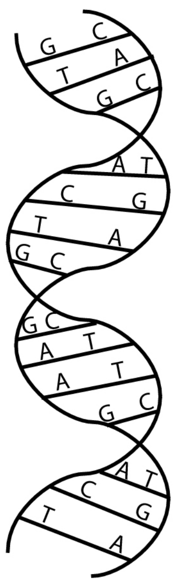


DNA, Genes and Chromosomes

Cells contain a set of large molecules called **DNA** (deoxyribonucleic acid). They tell the cell how to be the way it's supposed to be and do what it's supposed to do. The DNA is like an encyclopedia. Each cell has the complete set of information for every cell. But a cell only uses that part of the information that pertains to it.

Each "book" in the "encyclopedia" is called a **chromosome.** Each "article" on a particular subject is a **gene**. A gene is a part of a DNA molecule which has information for a particular trait such as what size the cell should be, or what chemicals it should react with. Because the information is ingenes, it is called genetic information. The chromosomes, each containing many, many genes, all made of DNA, are found in the nucleus.

Ionizing Radiation Can Damage DNA



Ionizing radiation has the ability to remove electrons from atoms. It can rearrange or erase the genetic information in the genes and chromosomes.

A DNA molecule is in the form of a long, spiral ladder. Each rung is a pairs of molecular bases. There are only four kinds of bases, called “A”, “C”, “G”and “T”. These “letters” form the language of the DNA “encyclopedia”. Different combinations spell out different pieces of genetic information. If a letter or group of letters were rearranged or erased, then they would provide useless or wrong information.

The “letters” are actually parts of a molecule. Molecules are made of atoms, and each atom has a cloud of electrons orbiting around it. The outer electrons on an atom “stick” to the outer electrons on another atom to hold the atoms together and form the molecule. If an electron is removed, then the bond between the atoms might be broken. The atoms might then rearrange themselves, forming a slightly different molecule. Some atoms might break off altogether, leaving part of the molecule missing. This is how the “letters” in the DNA encyclopedia might get rearranged or erased.

Ionizing radiation has the ability to remove electrons from atoms. It has the ability to disrrupt the atoms in DNA molecules causing them to rearrange or break off. **Ionizing radiation can rearrange or erase the genetic information in the genes and chromosomes.**

Each cell has the entire “encyclopedia”, but only uses a few “articles”, so it’s possible for the damage to be in a part of the DNA that the cell doesn’t need. It’s also possible that the cell recognizes the damage and repairs it. Or, it’s possible that the damage is so great that the cell no longer understand its own DNA, and dies.

Finally, it might be that the genetic information is changed and the cell starts to follow incorrect instructions. It behaves and grows differently than it’s supposed to do. It acts abnormally. This is when the genetic damage can cause cancer or reproductive effects.

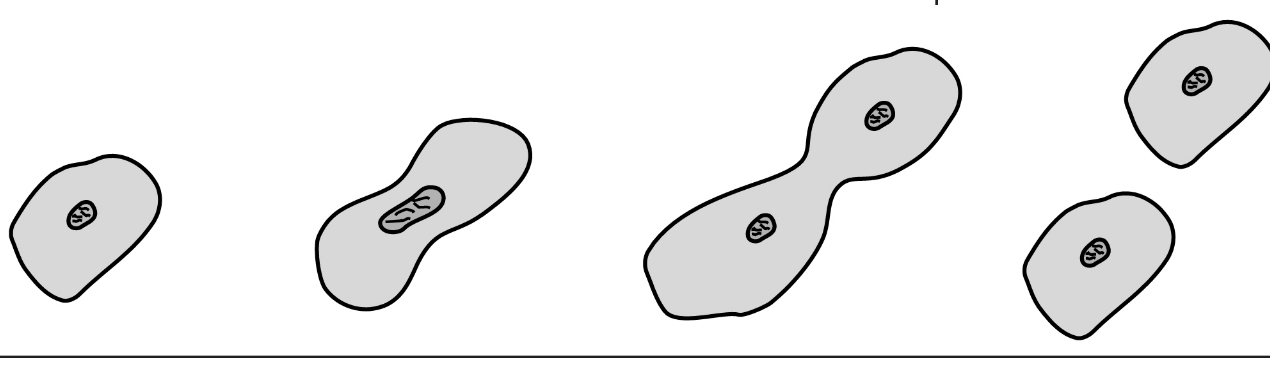
How Cells Divide

An individual cell can divide to make two new cells. The new cells are called “daughter” cells.

Cells divide for two reasons. First, it is how we grow. A human being develops from a single cell (which forms from the union of a sperm and an egg). That single cell divides to form two cells, each of which divide again, and again until there are the trillions of cells that make up a person. During this process the dividing cells also “differentiate” (specialize). Some become skin cells, some are brain cells, some are liver cells, etc.

The other reason that cells divide is to produce new cells that replace worn out ones. For example, cells in the lower layer of skin divide to make replacements for cells in the outer layer that have worn out and died. This process happens continuously since skins cell only live for a few days. A similar process happens inside the intestines, whose cells, like the skin, are constantly and quickly replaced. Cells in the scalp also divide quickly, in order for hair to grow. Other cells divide less rapidly. For example, cells in the brain and nervous system. A nerve cell lasts many years without dividing.

Cell division is illustrated below. First the chromosomes in the cell’s nucleus make a copy of themselves. Then the nucleus divides. Each of the two new nucleuses has a complete set of chromosomes. Then the cell itself divides. Each new cell has one of the nucleuses.



Cell Sensitivity To Ionizing Radiation

Some cells are more sensitive than others to environmental factors such as viruses, toxins and ionizing radiation. Radiation damage to cells may depend on how sensitive the cells are to radiation.

Actively dividing and nonspecialized cells. Cells in our bodies that are actively dividing are more sensitive to ionizing radiation. Cells that are rapidly dividing include: blood forming cells, the cells that line our intestinal tract, hair follicles, and cells that form sperm.

Less actively dividing and more specialized cells. Cells which divide at a slower pace or are more specialized (such as brain cells or muscle cells) are not as sensitive to damage by ionizing radiation.

Why Dividing Cells Are More Sensitive

When a cell is dividing, it's DNA is more easily damaged. The DNA gets stretched out so that it can be copied. It's weaker, and it presents a bigger target.

If the DNA is damaged, but the cell survives, then it might have incorrect information (some "letters" are rearranged or missing). This could affect how the cell behaves, and how often it divides. When the cell does divide it passes the incorrect information on to its "daughter" cells. These pass it on to their "daughters". This can create a whole group of cells that aren't doing what they are supposed to do, and which might be interfering with other cells that are trying to function normally. If this group of "bad" cells is big enough to cause problems and be noticed, it's called a **cancer**.

If the DNA in a cell in a developing fetus is damaged, then that cell might also have incorrect information and pass it on to other cells. These cells will divide again and again to form the different organs of the developing body. With wrong genetic information, a **birth defect** could result. This is why radiation exposure is especially hazardous for a developing fetus.

Possible Effects Of Radiation On Cells

When a cell is exposed to ionizing radiation, several things can happen. The following are possible effects:

• There is no damage

• Cells repair the damage and operate normally

The body of most cells is made up primarily of water. When ionizing radiation hits a cell, it is most likely to interact with the water in the cell. Often the cell can repair this type of damage. Ionizing radiation can also hit the nucleus of the cell. The nucleus contains the vital parts of the cell such as chromosomes. (The chromosomes determine the cell's function.) When chromosomes duplicate themselves, the chromosomes transfer their information to new cells. Damage to chromosomes, although often more difficult, can also be repaired. In fact, the average person repairs 100,000 chromosome breaks per day.

• Cells are damaged and operate abnormally

Cell damage may not be repaired or may be incompletely repaired. In that case, the cell may not be able to do its function or it may die. It is possible that a chromosome in the cell nucleus could be damaged but not be repaired correctly. This is called a mutation or genetic effect. We will discuss genetic effects when we consider chronic radiation doses.

• Cells die as a result of the damage

At any given moment, thousands of our cells are dying and being replaced by normal cells nearby. It is only when the dose of radiation is very high or is delivered very rapidly that the cell may not be able to repair itself or be replaced.

Four possible effects of ionizing radiation on cells:

1. **No damage.**
2. **Cell damaged, but repairs itself and functions normally.**
3. **Cell damaged, doesn't repair itself properly, and functions abnomally.**
4. **The cell dies.**

Acute And Chronic Radiation Doses

Potential biological effects depend on how much and how fast a radiation dose is received. Radiation doses can be grouped into two categories, **acute dose** and **chronic dose**.

We know that radiation therapy patients receive high doses of radiation in a short period of time but generally only to a small portion of the body (not a whole body dose). Ionizing radiation is used to treat cancer in these patients because cancer cells are rapidly dividing and therefore sensitive to ionizing radiation. Some of the side effects of people undergoing radiation therapy are hair loss, nausea and tiredness.

Acute Radiation Doses

An **acute effect** is a physical reaction due to massive cell damage. This damage may be caused by a large radiation dose received in a short period of time. Large doses of radiation received in a short period of time are called acute doses. The body can’t repair or replace cells fast enough from an acute dose and physical effects such as reduced blood count and hair loss may occur.

Slight blood changes may be seen at acute doses of 10,000-25,000 mrem but an individual would not otherwise be affected.

Radiation sickness. At acute doses greater than 100,000 mrem, about half of the people would experience nausea (due to damage of the intestinal lining). Radiation therapy patients often receive whole body equivalent doses in this range and above, although doses to the region of a tumor are many times higher than this.

Acute Radiation Doses (Continued)

If the acute dose to the whole body is very large (on the order of 500,000 mrem or larger) it may cause so much damage that the body cannot recover. An example is the 30 firefighters at Chernobyl who received acute doses in excess of 800,000 mrem. These individuals succumbed to the effects of the burns they received compounded by their radiation dose.

After an acute dose, damaged cells will be replaced by new cells and the body will repair itself, although this may take a number of months. Only in those extreme cases, such as with the Chernobyl firefighters, would the dose be so high as to make recovery unlikely.

Acute doses to only part of the body. It is possible in that radiation exposure may be only to a limited part of the body such as the hands. There have been accidents, particularly with X-ray machines, in which individuals have exposed their fingers to part of the intense radiation beam. In some of these cases individuals have received doses of millions of mrem to their fingers and some individuals have lost their finger or fingers. It is important for individuals who work with x-ray or similar equipment to be trained in the safe use of this equipment.

Probability of an acute dose. What is important to understand is that it takes a large acute dose of radiation before any physical effect is seen. These acute doses have only occurred in Hiroshima/Nagasaki, a few radiation accidents, and Chernobyl. The possibility of a radiological worker receiving an acute dose of ionizing radiation on the job is extremely low. In many areas where radioactive materials are handled, the quantities handled are small enough that they do not produce a large amount of radiation. Where there is a potential for larger exposures, many safety features are in place.

Chronic Radiation Doses

A **chronic radiation dose** is typically a small amount of radiation received over a long period of time. An example of a chronic dose is the dose we receive from natural background every day of our lives or the dose we receive from occupational exposure.

Chronic dose versus acute dose. The body is better equipped to handle a chronic dose than an acute dose. The body has time to repair damage because a smaller percentage of the cells need repair at any given time. The body has time to replace dead or non-functioning cells with new healthy cells. It is only when the dose of radiation is high and is received very rapidly that the cellular repair mechanisms are overwhelmed and the cell dies before repair can occur. A chronic dose of radiation does not result in detectable physical changes such as is seen with acute doses. Because of cell repair, even sophisticated analyses of the blood do not reveal biological effects.

Genetic effects. The biological effects of concern from a chronic dose is changes in the chromosomes of a cell and direct irradiation of a fetus. Genetic effects refer to effects to genetic material in a cell chromosome. Genetic effects can be somatic (cancer, etc.) or heritable (future generations).

Effects in the exposed individual (somatic effects). In this case, the individual has experienced damage to some genetic material in the cell that could eventually cause that cell to become a cancer cell. An example of a somatic effect is cancer. The probability of this is very low at occupational doses.

Heritable effects. A heritable effect is a genetic effect that is inherited or passed on to an offspring. In the case of heritable effects, the individual has experienced damage to some genetic material

Chronic Radiation Doses (Continued)

in the reproductive cells. Heritable effects from radiation have never been observed in humans but are considered possible and have been observed in studies of plants and animals. This includes the 77,000 Japanese children born to the survivors of Hiroshima and Nagasaki. These children were conceived after the atom bomb. Studies have followed these children, their children and grandchildren.

Factors Affecting Biological Damage

Total dose: In general, the greater the dose, the greater the potential of biological effects.

Dose rate (how fast): The faster the dose is delivered, the less time the cell has to repair itself.

Type of radiation: Alpha radiation is more damaging than beta or gamma radiation for the same energy deposited.

Area of the body receiving the dose: In general, the larger the area of the body that is exposed, the greater the biological effect. Extremities are less sensitive than internal organs. That is why the annual dose limit for extremities is higher than for a whole body exposure that irradiates the internal organs.

Cell sensitivity: The most sensitive cells are those that are rapidly dividing.

Individual sensitivity: Some individuals are more sensitive to ionizing radiation. The developing embryo/fetus is the most sensitive, and children are more sensitive than adults. In general, the human body becomes relatively less sensitive to ionizing radiation with increasing age. The exception is that elderly people are more sensitive than middle aged adults due to less efficient cell repair mechanisms.

Prenatal Radiation Exposure

Although no effects were seen in Japanese children conceived after the atomic bomb, there were effects seen in some children who were in the womb when exposed to the atomic bomb radiation at Hiroshima and Nagasaki.

Sensitivity of the unborn: Embryo/fetal cells are rapidly dividing which makes them sensitive to any environmental factors such as ionizing radiation.

Potential effects associated with prenatal exposures: Many chemical and physical (environmental) factors are suspected of causing or known to cause damage to an unborn child, especially early in the pregnancy. Alcohol consumption, exposure to lead, and heat from hot tubs are only a few that have been publicized lately. Some children who were exposed while in the womb to the radiation from the atomic bomb were born with a small head size and mental retardation. It has been suggested but is not proven that dose to the unborn may also increase the chance of childhood cancer. Only when the dose exceeds 15,000 mrem is there a significant increase in risk.

Limits are established to protect the embryo/fetus from any potential effects that may occur from a significant radiation dose. This may be the result of doses from external sources of radiation or internal sources of radioactive material. At present occupational dose limits, the actual risk to the embryo/fetus is negligible when compared to the normal risks of pregnancy.

Radiation and Cancer

Cancer is the uncontrolled growth of abnormal cells. It's when cells begin to "misbehave", and enough of these "cancer" cells grow so that they cause a problem.

For example, the cells in the lung form a structure which expands and contracts as you breathe. If some cells stop doing their proper function and instead grow into a mass that interferes with the passage of air or with normal expansion and contraction, then this is called lung cancer.

Cancer is the uncontrolled growth of abnormal cells that interfere with the way your body is supposed to work.

There are many kinds of cancer: liver, lung, breast, leukemia (blood cancer), bladder, skin, and so forth.

Cells "go bad" and become cancer cells because their DNA is damaged. We know that certain chemicals can do this. For example, insulation workers who were exposed to asbestos fibers are much more likely to get lung cancer, or a rare cancer called mesothelioma. Smokers have a much greater chance of getting lung cancer. We also know that ionizing radiation can cause DNA damage and lead to cancer, as discussed earlier.

Ionizing radiation has the ability to remove electrons from atoms. It can rearrange or erase the genetic information. This might lead to cancer.

Just because you're exposed to radiation or to a carcinogenic chemical doesn't mean you'll get cancer. The chemical or the radiation has to reach DNA in the cells of a target organ. The DNA has to be changed, but not damaged so badly that they die. The damage has to go unrepaired. Enough cancer cells have to grow so that they interfere with normal functioning. There are many steps, and most of the time they don't all happen. Most of the time exposure doesn't lead to cancer.

However, the more you are exposed, the more likely that all the bad steps will fall into line, and a cancer will grow. It's like lottery tickets. If you by one ticket you might win, but probably not. If you buy many tickets, your chances increase. In the cancer lottery, we want to buy as few tickets as possible. This why we want to keep exposures **as low as reasonably achievable.**

To decrease your risk, keep your exposure as low as reasonable achievable.

Risks In Perspective

Because ionizing radiation can damage the cell's nucleus, it is possible that through incomplete repair a cell could become a cancer cell.

Risk from exposures to ionizing radiation: No increases in cancer have been observed in individuals exposed to ionizing radiation at occupational levels. The possibility of cancer induction cannot be dismissed even though an increase in cancers has not been observed. Risk estimates have been derived from studies of individuals who have been exposed to high levels of radiation.

Comparison of risks: Acceptance of a risk is a highly personal matter and requires a good deal of informed judgment.

The risks associated with occupational radiation doses are considered acceptable as compared to other occupational risks by virtually all scientific groups who have studied them.

The following information is intended to put the potential risk of radiation into perspective when compared to other occupations and daily activities.

Table 1, on the next page, compares the estimated days of life expectancy lost as a result of exposure to radiation and other health risks. These estimates indicate that the health risks from occupational radiation doses are smaller than the risks associated with normal day-to-day activities that we have grown to accept.

Table 2 addresses the estimated days of life expectancy lost as a result of radiation doses received and common industrial accidents at radiation-related facilities. It compares these numbers to days lost as a result of fatal work-related accidents in other occupations.

Comparing Health Risks

Table 1

Average estimated days lost due to daily activities

Health Risk	Estimated Days Lost
Unmarried male	3500
Cigarette smoking	2250
Unmarried female	1600
Coal miner	1100
25% overweight	777
Alcohol (U.S. average)	365
Construction worker	227
Driving a motor vehicle	207
100 mrem/year for 70 years	10
Coffee	6

Table 2

Average estimated days lost in various occupations

Industry	Estimated Days Lost
Mining/Quarrying	328
Construction	302
Agriculture	277
Radiation dose of 5,000 mrem/yr. for 50 yrs.	250
Transportation/Utilities	164
All Industry	74
Government	55
Service	47
Manufacturing	43
Trade	30
Radiation accidents (deaths from exposure)	<1

Practice Questions

1. The average non-occupational exposure to the general public from man-made sources and natural background is ___________ mrem per year.

2. What are the four sources of natural background radiation?

a. ____

b. ____

c. ____

d. ____

3. How does radiation interact with the atoms in cells to cause damage?

____

____

____

4. What are the possible effects of radiation on cells?

a. ____

b. ____

c. ____

d. ____

Practice Questions (Continued)

5. Exposure from natural background is considered to be what type of an exposure? ______________
____

6. A dose received from an accident such as Chernobyl, would be what type of a dose?
____

7. If you as a radiological worker showed an effect from exposure to radiation, what type of an effect would this be?
____

8. If your child or grandchild showed an effect from radiation dose that you as a radiological worker received prior to conception, what type of effect would this be?
____

9. What are the three potential effects from prenatal exposure?

a. ____

b. ____

c. ____

Chapter

3

Radiation Limits

Learning Objectives

Upon completion of this unit, the participant will be able to IDENTIFY restrictions regarding dose limits and administrative control levels.

The participant will be able to SELECT the correct response from a group of responses which verifies his/her ability to:

EO 1. STATE the purposes of the Facility administrative control levels.

EO 2. IDENTIFY the DOE radiation dose limits, DOE administrative control level and Facility administrative control levels.

EO 3. STATE the site policy concerning prenatal radiation exposure.

EO 4. IDENTIFY the employee's responsibility concerning radiation dose limits and administrative control levels.

EO 5. DESCRIBE the action a worker should take if he or she suspects that dose limits or administrative control levels are being approached or exceeded.

Dose Limits and Control Levels

In order to minimize the biological effects associated with radiation, **radiation dose limits** and **administrative control levels** have been established.

The DOE radiation dose limits are set for occupational workers based on guidance from the Environmental Protection Agency (EPA), the National Council on Radiation Protection and Measurements (NCRP), and the International Commission on Radiological Protection (ICRP). These limits are also consistent with the “Radiation Protection Guidance to Federal Agencies for Occupational Exposure” signed by the President of the United States.

DOE also sets **DOE administrative control levels** which are lower (more protective) than the radiation dose limits. The purpose of the DOE administrative control levels is to keep exposures even lower.

The **Facility administrative control levels** for radiological workers are lower than the DOE limits and are set to ensure that the DOE limits and administrative control levels are not exceeded. They also help reduce individual and total worker population (collective dose) radiation dose.

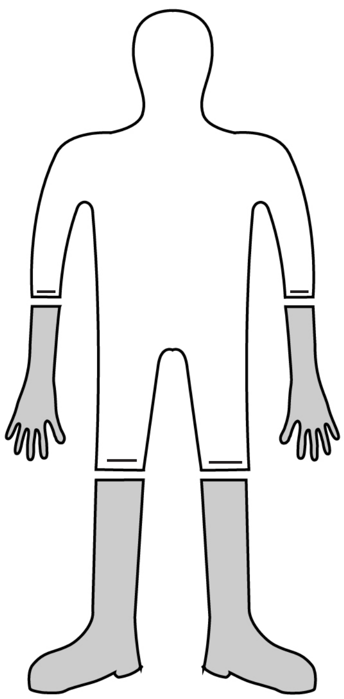
There are different radiation limits and control levels for different parts of the body. This is because some parts of the body are considered to be more sensitive to the effects of ionizing radiation.

There are also different limits for different classes of people (radiological workers, declared pregnant female workers and members of the public).

Finally, there are different guidelines for radiological emergency situations, as opposed to routine work. We will discuss these emergency limits in Chapter 8.

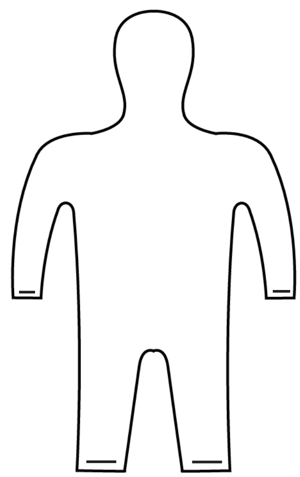
Different Limits For Different Parts Of The Body

We divide the entire body into two regions: the **whole body** and the **extremities**. There are also separate limits for the **skin**, the **lens of the eye**, **individual organs,** and the **embryo** or **fetus.**

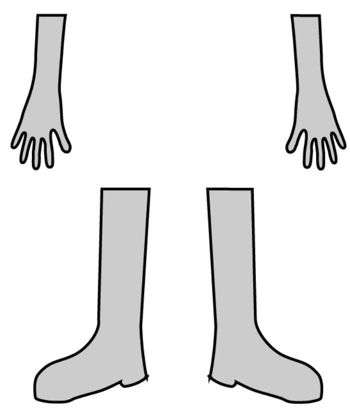


The entire body is divided into two regions:
1) the "whole body" and
2) the "extremities."

Definition: the **whole body** extends from the top of the head down to just below the elbows and just below the knees. This is the location of most of the blood-producing and vital organs.



Definition: The **extremities** include the hands and arms below the elbow and the feet and legs below the knees.



Whole Body

There are limits for external radiation dose and there are limits for internal radiation dose. Internal dose results from radioactive material being inhaled, ingested, or absorbed through the skin or a wound. Limits are based on the sum of internal and external doses.

The DOE radiation dose limit for the **whole body** during routine conditions is **5 rem/year**. Since DOE's objective is to maintain radiation doses to personnel well below the regulatory limits, a DOE administrative control level has been established.

Limits are based on the sum of internal and external doses.

The DOE administrative control level for the whole body during routine conditions is **2 rem/year.**

The facility administrative control level for the whole body during routine conditions is _______________.

Extremities

Extremities can withstand a much larger dose than the whole body since there are no major blood-producing organs located there.

The DOE radiation dose limit for the extremities during routine conditions is **50 rem/year**.

The facility administrative control level for the extremities during routine conditions is _______________.

Skin And Other Organs

The DOE radiation dose limit for skin and other organs during routine conditions is **50 rem/year.**

The facility administrative control level for skin and other organs during routine conditions is _______________.

Lens of the Eye

The DOE radiation dose limit for the lens of the eye during routine conditions is **15 rem/year**.

The facility administrative control level during routine conditions is _______________.

Declared Pregnant Worker

DOE policy: A female worker is encouraged to voluntarily notify her employer, in writing, when she is pregnant. When she has done so, the employer must provide the option of a mutually agreeable job, with no loss of pay or promotional opportunity, such that further occupational radiation exposure is unlikely. This declaration may be withdrawn, in writing, at any time by the declared pregnant worker.

DOE limit: For a declared pregnant worker who continues working as a radiological worker, the dose limit for the embryo/fetus (during the entire gestation period) is 500 mrem. Efforts should be made to avoid exceeding 50 mrem/month to the pregnant worker. If the dose to the embryo/fetus is determined to have already exceeded 500 mrem, the worker shall not be assigned to tasks where additional occupational radiation exposure is likely during the remainder of the pregnancy.

The facility administrative control level for a declared pregnant worker is _______________.

Members of the Public

The DOE radiation dose limit for members of the public is **0.100 rem/year.**

The facility administrative control level for members of the public is _______________.

Summary of Radiation Dose Limits and Control Levels			
	DOE Radiation Dose Limit	DOE Administrative Control Level	Facility Administrative Control Level (2)
Whole Body	5 rem / year	2 rem / year	
Extremities	50 rem / year	30 rem / year	
Skin and other organs	50 rem / year	30 rem / year	
Lens of the eye	15 rem / year	9 rem / year	
Embryo / fetus	500 mrem / year	(1) xxxxx	
Members of the public & minors	100mrem/year	(1) xxxxx	

Notes: 1) xxxxxxxx indicates that the DOE Radiation Dose Limit applies.
2) Enter the Facility Administrative Control Levels for your facility.

Worker Responsibilities Regarding Dose Limits

It is each employee's responsibility to comply with DOE dose limits, control level and facility administrative control levels.

If you suspect that dose limits or administrative control levels are being approached or exceeded, you should notify your supervisor immediately.

Practice Questions

1. What is the purpose of the facility administrative control levels?

____

____

2. What are the DOE radiation dose limits for the following:

a. Whole body: ____________________________

b. Eyes: ____________________________________

c. Skin: ____________________________________

d. Extremities: ______________________________

3. What is the site policy for prenatal radiation exposure?

____

____

____

4. As you approach your radiation dose limits, whom should you notify?

____

Chapter

4

The ALARA Program

Learning Objectives

Upon completion of this unit, the participant will be able to EXPLAIN the methods used to implement the site ALARA Program.

The participant will be able to SELECT the correct response from a group of responses which verifies his/her ability to:

EO 1. STATE the ALARA concept.

EO 2. STATE the DOE/Site management policy for the ALARA program.

EO 3. IDENTIFY the responsibilities of management, Radiological Control Organization and the radiological worker in the ALARA Program.

EO 4. IDENTIFY the basic protective measures of time, distance and shielding.

EO 5. IDENTIFY methods for reducing external and internal radiation dose.

EO 6. STATE the pathways by which radioactive material can enter the body.

EO 7. IDENTIFY methods a radiological worker can use to minimize radioactive waste.

Introduction To This Chapter

This unit is designed to inform the student of the **ALARA** concept (**A**s **L**ow **A**s **R**easonably **A**chievable). While **ALARA** is a concept that can apply to any biological hazard, just the radiation hazards will be addressed. Methods for reducing both external and internal doses from radiation and radioactive material are also discussed.

Even though there are dose limits and administrative control levels, we strive to keep our radiation dose well below these. Employees should always try to maintain their radiation dose **A**s **L**ow **A**s **R**easonably **A**chievable **(ALARA)**.

ALARA

ALARA means reducing both internal and external exposures.

ALARA stands for: **A**s **L**ow **A**s **R**easonably **A**chievable.

Since some risk, however small, exists from any radiation dose, all doses should be kept ALARA. ALARA includes reducing both internal and external radiation dose. ALARA is an integral part of all site activities that involve radioactive materials.

DOE ALARA Policy

Personal radiation exposure shall be maintained As Low As Reasonably Achievable. Radiation exposure of the work force and public shall be controlled so that:

- Radiation exposures are well below regulatory limits.
- There is no occupational radiation exposure without an expected benefit.

Responsibilities For The ALARA Program

ALARA is the responsibility of all employees.

Although the individual radiation worker is ultimately responsible for maintaining his/her radiation dose ALARA, management and Radiological Control personnel also play an important role in the ALARA program. The following are some of the responsibilities of the three groups: Management, the Radiological Control Organization and Radiological Workers.

Radiological Control Organization Responsibilities For ALARA

The Radiological Control Organization is responsible for implementing the ALARA program at the Site. It is also responsible for implementing the requirements for the entire Radiological Control program. These requirements are established in DOE Orders, the DOE Radiological Control Manual, and Site Radiological Control documents.

Radiological Control Technicians (RCTs) provide a point of contact for the worker to obtain the most current radiological conditions in an area. RCTs provide assistance when trying to interpret protective requirements or radiological information concerning a work assignment and they address radiological questions/concerns.

Worker Responsibilities For ALARA

Each person involved in radiological work is expected to demonstrate responsibility and accountability through an informed, disciplined and cautious attitude toward radiation and radioactivity.

Reducing External Dose

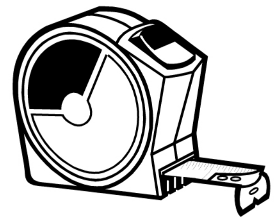
Basic protective measures used to reduce external dose include minimizing **time** in radiation areas, maximizing the **distance** from a source of radiation and using **shielding** whenever possible.

Minimizing Time

Reducing the amount of time spent in a Radiation Area will lower the dose received by the workers.

- Plan and discuss the task prior to entering the area. Use only the number of workers actually required to do the job.
- Have all necessary tools present before entering the area.
- Use mock-ups and practice runs that duplicate work conditions.
- Take the most direct route to the job site if possible and practical.
- Never loiter in a radiological area.
- Work efficiently and swiftly.
- Do the job right the first time.
- Perform as much work outside the area as possible. When practical, remove parts or components to areas with lower dose rates to perform work.
- In some cases, the Radiological Control personnel may limit the amount of time a worker may stay in an area due to various reasons. This is known as “stay time”. If you have been assigned a stay time, do not exceed this time.

Maximizing Distance



- The worker should stay as far away from the source of radiation as possible.

- For point sources, such as valves and hot spots, the dose rate follows a principle called the inverse square law. This law states that if you double the distance, the dose rate falls to 1/4 of the original dose rate. If you triple the distance, the dose rate falls to 1/9 of the original dose rate.

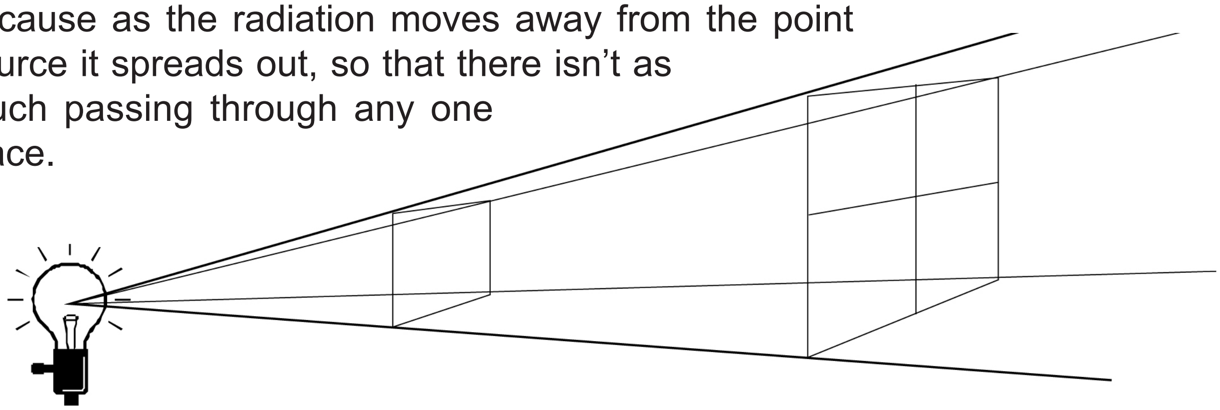
- Be familiar with radiological conditions in the area.

- During work delays, move to lower dose rate areas.

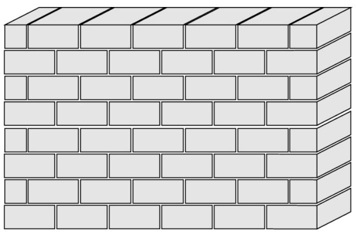
- Use remote handling devices when possible.

The Inverse Square Law

If a radiation source is small in size, it's called a point source because the radiation appears to come from just one point. Distance is a very good means of decreasing exposure from a point source because the intensity of the radiation obeys something called the **inverse square law**. As you get further from a point source, the radiation level drops off in proportion to the square of the change in distance. For example, if you go two times as far away, the radiation is four times lower. (4 is the square of 2). If you go three times as far away, the level is nine times as low. Four times further away; sixteen times lower, etc. This is because as the radiation moves away from the point source it spreads out, so that there isn't as much passing through any one place.



Proper Use of Shielding



Shielding reduces the amount of radiation dose to the worker. Different materials shield a worker from the different types of radiation.

- Take advantage of permanent shielding including non-radiological equipment or structures.

- Use shielded containments when available.

- Wear safety glasses or goggles to protect your eyes from beta radiation, when applicable.

- Temporary shielding (e.g., lead or concrete blocks) can only be installed when proper procedures are used. Temporary shielding will be marked or labeled with wording such as, "Temporary Shielding - Do Not Remove Without Permission from Radiological Control." Once temporary shielding is installed, it cannot be removed without proper authorization.

- It should be remembered that the placement of shielding may actually increase the total dose (e.g., person-hours involved in installing and removing shielding).

Source Reduction

Source reduction normally involves procedures such as flushing radioactive systems, decontamination, etc., to reduce the amount of radioactive materials in or on a system that can add to radiation levels in an area.

Reducing Internal Dose

Internal dose is the result of radioactive material being taken into the body. Radioactive material can enter the body through one or more of the following pathways:

- Inhalation
- Ingestion
- Absorption through the skin
- Absorption through the wounds

Methods to Reduce Internal Dose

Reducing the potential for radioactive materials to enter the body is important. The following are methods the worker can use:

- Wear respirators correctly when required (if you have been qualified for respirator use).
- Report all wounds or cuts (including scratches and scabs) to the appropriate site-specific organization before entering any area controlled for radiological purposes.
- Comply with the requirements of the controlling work documents.
- Do not eat, drink, smoke or chew in areas controlled for radiological purposes.

Radioactive Waste Minimization

One of the consequences of working in and around radioactive materials is that radioactive waste will be generated. This radioactive waste must be disposed of. Examples of radioactive waste include:

- paper
- gloves
- glassware
- rags
- brooms, mops

To reduce doses to personnel, and to reduce costs associated with the handling, packaging and disposal of radioactive waste it is very important for each employee to minimize the amount of radioactive waste generated.

Methods To Minimize Radioactive Waste

Minimize the materials used for radiological work:

- Take only the tools and materials you need for the job into areas controlled for radiological purposes especially contamination areas.
- Unpack equipment and tools in a clean area to avoid bringing excess clean material to the job site.
- Whenever possible, use tools and equipment identified for radiological work. If you do not know where to get tools that are to be used for radiological work, ask your supervisor.
- Use only the materials required to clean the area. An excessive amount of bags, rags, and solvent adds to radioactive waste.

Separate Radioactive Waste From Non-radioactive Waste

- Place radioactive waste in the containers identified for radioactive waste, not in containers for non-radioactive waste.
- Do not throw non-radioactive waste, or radioactive material that may be reused, into radioactive waste containers.
- Separate compactible material from non-compactible material.

Minimize The Amount Of Waste Generated

- Mixed waste is waste that contains both radioactive and hazardous materials.
- Use good housekeeping techniques.

Practice Questions

1. DOE radiation ALARA policy applies to:
   (Check all those that apply.)

a. ___ Radiation exposures.

b. ___ Contamination exposures.

c. ___ Asbestos exposures.

d. ___ Cosmic radiation exposures.

e. ___ Chemical exposures.

f. ___ Medical X-Rays.

2. DOE Management policy is designed to keep radiation doses well below regulatory limits and that there is no occupational radiation dose without _________________________.

3. Who provides a point of contact for the workers to obtain the most current radiological conditions in an area?
   ____

4. The basic protective measures for ALARA are:
   (Check all that apply.)

a. ___ Maximizing time in an area.

b. ___ Minimizing time in an area.

c. ___ Maximizing distance in an area.

d. ___ Minimizing distance in an area.

e. ___ Maximizing shielding in an area.

f. ___ Minimizing shielding in an area.

Practice questions continue on the next page.

Practice Questions (Continued)

5. List five methods to reduce the amount of time spent in a radiation area.

a. ____

b. ____

c. ____

d. ____

e. ____

6. Which of the following are pathways radioactive material may enter the body?

a. ___ Chewing gum in a contamination area.
b. ___ Entering a radiation area without proper dosimetry.
c. ___ Entering radiological areas.
d. ___ Not wearing a respirator when required by procedure.
e. ___ Receiving an x-ray from medical.
f. ___ Working with radioactive materials that can be absorbed through the skin without protective equipment.

7. Radioactive waste can be minimized by: (Check all that apply.)

a. ___ Minimize materials used for radiological work.
b. ___ Separate radioactive waste from non-radioactive waste
c. ___ Use only tools and materials required in radiological areas.
d. ___ Minimize mixed waste.

Chapter

5

Personnel Monitoring

Learning objectives

Given different personnel monitoring programs, IDENTIFY the purpose, types and worker responsibilities for each.

The participant will be able to SELECT the correct response from a group of responses which verifies his/her ability to:

EO 1. STATE the purpose of each of the personnel dosimeter devices used at the site.

EO 2. IDENTIFY worker responsibilities concerning each of the external personnel dosimeter devices used at the site.

EO 3. STATE the purpose of each type of internal monitoring method used.

EO 4. IDENTIFY worker responsibilities concerning internal monitoring programs.

EO 5. STATE methods for obtaining radiation dose records.

EO 6. IDENTIFY worker responsibilities for reporting radiation dose received from other sites and from medical applications.

Introduction To This Chapter

Each employee's external and internal dose to ionizing radiation is assessed using special types of monitoring equipment. The types used depend on the radiological conditions present.

Because different conditions and exposures exist at different facilities, the types of monitoring equipment (dosimetry) may be different at different sites. Also, different sites may use different names for certain types of monitoring equipment.

External Dosimetry

A dosimeter is a device that is used to measure radiation dose. Dosimeters used to measure external sources of radiation are called external dosimeters. In this chapter we discuss the purpose of each of the external dosimeter devices used (including basic principles of operation of types commonly used at the site).

List the types of external dosimetry used at your site:

1. ____

2. ____

3. ____

4.____

Worker Responsibilities For External Dosimetry

- Wear dosimeters at all times in areas controlled for radiological purposes when required by signs, work permits or Radiological Control personnel. Primary dosimeters are worn on the chest area, between the waist and the neck in a manner directed by radiological control personnel.

- Wear supplemental dosimeters (e.g., pocket, electronic, neutron) when required, in accordance with site policy.

- Take proper actions if dosimeter is lost, off-scale, damaged or contaminated while in an area controlled for radiological purposes. These actions include:

The first letters of these procedures spell the word "PAIN".

- **P**lace work activities in a safe condition

- **A**lert others

- **I**mmediately exit the area

- **N**otify Radiological Control personnel

- Know the proper dosimeter storage location.

- Return dosimeters for processing periodically. Personnel that fail to return dosimeters will be restricted from continued radiological work.

- Dosimeters issued from the permanent work site cannot be worn at another site.

Thermo-Luminescent Dosimeter (TLD)

Purpose: The **thermoluminescent dosimeter (TLD)** is a badge which the worker wears, usually clipped to the shirt pocket, or to a strap on the worker's anti-c's. There are TLD's which measure beta, gamma and neutron radiation exposure.

On a regular schedule (monthly or quarterly, for example) the TLD is sent to the laboratory to be read. The results of the TLD readings are maintained by the facility as the legal record of the worker's occupational radiation exposure.

The TLD provides the legal record of your radiation exposure.

Principle of operation: Inside its plastic case, the TLD contains special crystals which absorb energy from ionizing radiation. This energy causes electrons in the crystals to move to a higher orbit.

"thermo" = heat. "luminescent" = gives off light.

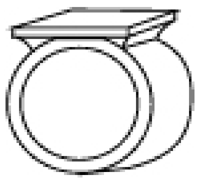
Later, in the dosimetry laboratory, the TLD is placed in a processor which heats the crystals. When the crystals are heated, they give off a small amount of light as the electrons drop back to their normal orbit. The more radiation the TLD absorbed, the more light the crystals release. The processor measures this light and determines the radiation dose.

If the front of the TLD is not facing forward, it won't measure all of the radiation to which you are exposed.

Proper use: Because the TLD is used to establish the legal record of your radiation exposure, it is important that you wear it at all required times, and that you wear it properly. It should be worn in front, between your neck and your waist. Make certain that the front of the TLD is facing out.

There is usually a rack in which you place your TLD when you leave the area in which it is required. Generally you should not take the TLD home at the end of your shift!

Finger ring

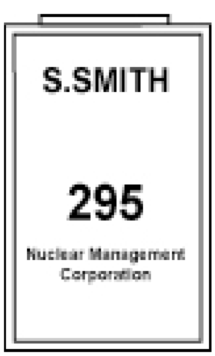


Purpose: This dosimeter measures radiation dose to the hands. This information is also recorded as part of the legal record of your radiation exposure.

Principle of operation: The ring dosimeter has the same type of crystals used in regular TLD's. It is read in the laboratory in the same manner.

Proper use: A finger ring is worn on any finger except the thumb, with the TLD chip facing the radiation source. Often this means that the chip faces the palm of the hand, in order to measure exposure from materials that the worker handles. If the source of exposure is located above the worker's hands, then the TLD chip should face outward.

Film Badge



Purpose: Film badges can be used to measure exposure to gamma and x-rays, as well as beta and neutron particles.

Principle of operation: The film badge contains photographic film, and one or more filters. If the film is exposed to ionizing radiation, it darkens. On a regular schedule the badge is opened in the laboratory and the film is developed. The darker the film, the greater the radiation exposure that is indicated. The filters affect how much radiation gets to certain parts of the film. Higher energy radiation (gamma, x-ray, and neutron) can penetrate the filters more easily than lower energy radiation (beta) .The darkness of different parts of the film indicates how penetrating the radiation was.

Proper use: Film badges can be damaged by heat, light and moisture. Don't leave the badge anywhere that the temperature gets above 124ºF. If the case of the badge is torn or punctured, light will enter and ruin the film. Don't let the badge get soaking wet.

Self Reading Pocket Dosimeter (SRPD)

(DRD)

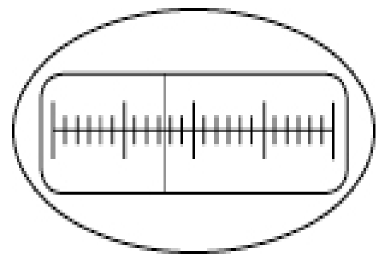
(PIC)

This dosimeter has several different names:

- Self reading pocket dosimeter (SRPD),
- Direct reading dosimeter (DRD),
- Pocket ionization chamber (PIC), and
- Quartz fiber dosimeter.

Purpose: This dosimeter measures gamma and x ray exposure. The worker can read this dosimeter at any time. It does not have to be sent to the laboratory to be read. It provides an immediate, on the spot estimate of radiation exposure.

Principle of operation: The dosimeter contains two tiny quartz fibers. Before the dosimeter is issued to a worker, it is charged (zeroed) in the laboratory with a small electric charge which causes the fibers to separate. When the fibers are exposed to gamma or x radiation, the charge is reduced, and the fibers move closer together. To read the dosimeter, hold it up to the light. You will see a line across the numbered scale. That line is actually one of the fibers. Where it is on the scale indicates how much radiation it has been exposed to.



Proper use: Wear this dosimeter near your TLD. Read it before you begin the job assignment, regularly during the job, and at the end of your work. In a high radiation area, read the dosimeter at least once every 10 minutes. The radiological work permit (RWP) may require more frequent reading. Don't drop or bang the dosimeter. This can change the reading. If the reading rises sharply or goes off scale, or if you damage or lose the dosimeter, follow the "PAIN" procedure indicated previously in Worker Responsibilities.

Electronic Dosimeters

(PADI)

Purpose: These dosimeters usually measure only gamma or x radiation. They are worn by the worker. Some of these dosimeters have a digital display. Others are “churpers”. They emit a series of audible “churps”. The more frequent the churps, the higher the exposure rate. Some dosimeters have an alarm which indicates that exposure is greater than a predetermined level. One type is called a **pocket alarm dose indicator (PADI).**

Principle of operation: The exact principle of operation depends on the make and model.

Proper use: Follow the instructions which come with the dosimeter. Follow the requirements on the radiological work permit (RWP). If you are not certain about how to use the dosimeter, ask your supervisor.

Internal Monitoring

Whole body counters, lung counters, and/or bioassay samples may be used to determine the kinds, quantities or concentrations of radioactive material in the human body. In some cases, locations of radioactive material in the human body may be determined. An internal dose may be calculated from these measurements.

Whole Body Counter

The **whole body counter** measures radiation emitted by radioactive materials within the body. You may be expected to receive a whole body count at the beginning and end of your employment, at regular intervals during employment, or after a suspected over exposure. The whole body counter is a laboratory instrument, set up in a special room which is heavily shielded from all outside sources of radiation. Do not confuse the “whole body counter” with a “whole body frisk” or a “personal contamination monitor.”

Bioassay

A **bioassay** is a laboratory analysis of urine or feces to determine if radioactive materials are present in these body materials. By measuring both the quantity of radioactive material eliminated, and its rate of elimination, it is possible to calculate internal radiation doses for certain isotopes. Bioassays can be used to measure all types of radioactive materials in bodily wastes, not just the gamma emitters that whole body counters measure.

You may be required to provide bioassay samples on a regular schedule, or following certain job assignments where an accidental internal contamination is a possibility.

Worker Responsibilities

Each radiological worker is responsible to:

- Provide bioassay samples for analysis as required or when requested.
- Appear when requested for a whole body count.

To Obtain Your Radiation Dose Records

In order to obtain your own radiation dose records:

- Personnel who are monitored with dosimeters will be provided an annual report of their radiation dose.
- Detailed information concerning any individual's exposure shall be made available to the individual upon request of that individual.
- Terminated personnel will receive a report of the radiation dose received at that site.

Reporting Other Doses Received

You are responsible for reporting other radiation doses:

- Notify Radiological Control personnel, prior to and following, of any radiation dose received at another facility so that dose records can be updated.
- Report medical applications (this does not include routine medical and dental x rays).

Practice Questions

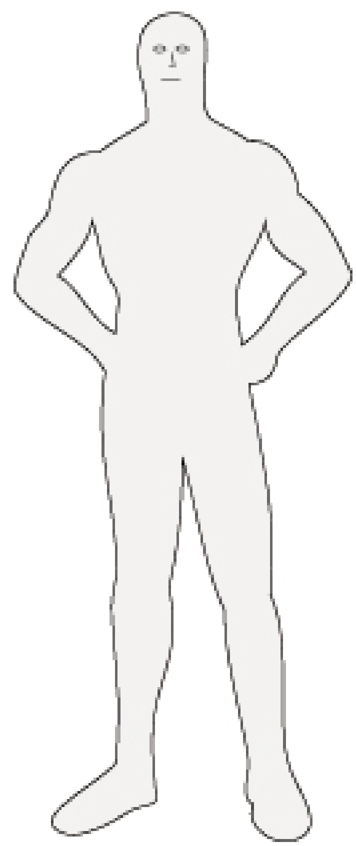
1. The purpose of external dosimetry is to:

a. Measure dose from all ionizing radiation sources.
b. Measure dose from natural sources of ionizing radiation.
c. Measure dose from occupational radiation.
d. Measure dose from medical sources.

2. External dosimetry measures which of the following:

a. Radiation emitted from the drum and radiation from the leak.
b. Contamination leaking from the drum and contamination found inside the drum.

3. Draw a dosimeter in the proper location on the person at the right.



4. Internal monitoring provides detection of the following (check all that apply):

___ a. Natural sources - food, soil, etc.
___ b. Man-made sources - medical.
___ c. Occupational sources.
___ d. Non-ionizing sources.

5. Examples of internal monitoring are (check all that apply)

___ a. Whole body counter.
___ b. External dosimetry.
___ c. Bioassay.
___ d. Personal contamination monitor (PCM).

Practice Questions (Continued)

6. Dose reports are provided on an annual basis.

True_____
False____

7. Workers may get their current dose record via:

a. Their supervisor.
b. The medical department.
c. Written request.
d. The security department.

8. For dose received at another site the radiological worker must notify their Radiological Control Organization before and after the dose is received.

True_____
False____

9. You must notify the Radiological Control Organization for the following (check all that apply)

___ a. Dental x-rays
___ b. Radiation exposure received at another site.
___ c. Sunburn.
___ d. Chest x-ray.
___ e. Injection of radioactive isotopes for medical purposes.
___ f. Lost dosimeter.

Chapter

6

Radiological Postings and Controls

Learning Objectives

Upon completion of this unit, the participant will be able to DISCUSS general radiological postings and job specific Radiological Work Permits.

The participant will be able to SELECT the correct response from a group of responses which verifies his/her ability to:

EO 1. STATE the purpose of and information found on Radiological Work Permits (RWPs).

EO 2. IDENTIFY the worker's responsibilities in using Radiological Work Permits.

EO 3. IDENTIFY the colors and the symbol used on radiological postings.

EO 4. STATE the radiological and disciplinary consequences of disregarding radiological postings, signs and labels.

EO 5 DEFINE the areas controlled for radiological purposes.

EO 6. IDENTIFY the minimum requirements for entering, working in, and exiting:

a. Radiological buffer areas.
b. Radiation areas.
c. Radioactive material areas.
d. Underground radioactive material areas.
e. Soil contamination areas.
f. Fixed contamination areas.

EO 7. IDENTIFY the purpose and use of personnel contamination monitors.

Radiological Work Permits (RWP's)

RWPs are used to establish radiological controls for entry into areas controlled for radiological purposes. They serve to inform workers of area radiological conditions, entry requirements into the areas, and provide a means to relate radiation doses received by workers to specific work activities.

There are two types of Radiological Work Permits:

1. **General Radiological Work Permit**.
2. **Job Specific Radiological Work Permit**.

General RWP

A **General Radiological Work Permit** is used to control routine or repetative activities such as tours and inspections in areas with historically stable radiological conditions. It is valid for one year.

Job Specific RWP

A **Job Specific Radiological Work Permit** is used to control non-routine operations or work in areas with changing radiological conditions. It is valid for the duration of a particular job.

RWP Forms

There is no required form for the RWP. This means that RWP's from different facilities may look different. However, DOE requires that certain information be included in an RWP. This information is specified on the following page.

RWP Contents

The RWP shall include the following information:

- Description of work.
- Work area radiological conditions. This information may also be determined from area radiological survey maps/diagrams or the radiological posting for that area.
- Dosimetry requirements.
- Pre-job briefings (as applicable). Pre-job briefings generally consist of workers and supervisor(s) discussing various radiological aspects and controls of the job. This is done to minimize radiological exposure and unplanned situations.
- Required level of radiological training for entry.
- Protective clothing and protective equipment requirements.
- Radiological Control coverage requirements and stay time controls, as applicable.
- Limiting radiological conditions which may void the permit.
- Special dose or contamination reduction considerations.
- Special personnel frisking considerations.
- Technical work document and other unique identifying numbers.
- Date of issue and expiration.
- Authorizing signatures.

Worker RWP Responsibilities

Each worker who enters an area for which an RWP is required has the following responsibilities:

- Workers must read and comply with the RWP requirements.
- Workers must acknowledge by signature that they have read, understood, and will comply with the RWP prior to entering the radiological area.
- If you believe the RWP is incorrect or you don't understand any of the information, contact Radiological Control personnel or your supervisor prior to beginning work.
- Do not make substitutions for specified requirements. The use of protective clothing or equipment beyond that specified by the Radiological Control Organization is not authorized.
- Report to Radiological Control personnel if radiological controls are not adequate or are not being followed.

Radiological Postings

Radiological postings are used to:

- Alert personnel to the presence of radiation and radioactive materials.

- Aid in minimizing personnel dose.

- Prevent the spread of contamination.

Posting Requirements

Areas and materials controlled for radiological purposes will be designated with a magenta (or black) standard three-bladed radiological warning symbol (trifoil) on a yellow background.

- Fixed barriers (walls, rope, tape or chain) will designate the boundaries of posted areas. Where possible, the barriers will be yellow and magenta.

- The barriers should be placed to clearly mark the boundary of the radiological areas. Controlled Areas may use the buildings as the barrier.

- Entrance points to radiologically controlled areas will have signs (or postings) stating the entry requirements, such as, "Personnel Dosimeters, RWP and Respirator Required."

- In some cases, more than one radiological hazard may be present in the area. The area will be posted with all radiological hazards that are present.

- In areas of on-going work activities, the dose rate and contamination levels (or ranges of each) may be included if applicable.

- The posting should be placed where it is clearly visible to personnel.

Worker Responsibilities for Postings. Signs And Labels

Before entering an area controlled for radiological purposes, read all of the signs. Since radiological conditions can change, the signs will also be changed to reflect the new conditions. A sign or posting that you saw one day may be replaced with a new one the next day.

Obey any posted, written or oral requirements including “Exit”, “Evacuate”, “Hold Point” or “Stop Work Orders”, from the Radiological Control personnel.

- Hold points are specific times noted in a procedure, work permit, etc. where work must stop for Radiological Control evaluations.

- Stop Work Orders are usually a result of:

- Inadequate radiological controls,

- Radiological controls not being implemented, or

- Radiological hold point not being observed.

Report unusual conditions to the Radiological Control personnel such as leaks or spills, dusty or hazy air, and alarming area monitors.

Be aware of changing radiological conditions.
Be aware that others’ activities may change the radiological conditions in your area.

If any type of material used to identify radiological hazards is found outside an area controlled for radiological purposes, it should be reported to Radiological Control personnel immediately.

Consequences of Disregarding Radiological Postings, Signs and Labels

It is each worker's responsibility to read and comply with all the information identified on radiological postings, signs and labels. Disregarding any of these or removing/relocating them without permission can cause:

- Unnecessary or excessive radiation dose.
- Personnel contamination.
- Disciplinary actions such as a formal reprimand or suspension.

Requirements for Entry, Exit and Working in Radiologically Posted Areas

The following are the various areas controlled for radiological purposes.

Radiation Areas.
- Radiation Area.
- High Radiation Area.
- Very High Radiation Area.

Contamination Areas.
- Contamination Area.
- High Contamination Area.
- Fixed Contamination Area.
- Airborne Radioactivity Area.
- Soil Contamination Area.

- **Radiological Buffer Areas.**

Other Radiological Areas.
- Radioactive Materials Area.
- Underground Radioactive Materials Area.

The requirements for each of these areas are discussed on the following pages.

Radiological Buffer Area

Radiological buffer areas (RBA) provide secondary boundaries to minimize the spread of radioactive contamination and to limit doses to general employees who have not been trained as radiological workers.

Posting Requirement:

"CAUTION, RADIOLOGICAL BUFFER AREA"

Minimum requirements for unescorted entry:

- Radiological Worker I Training
- Personnel dosimetry, as appropriate

Requirements for working in RBA's:

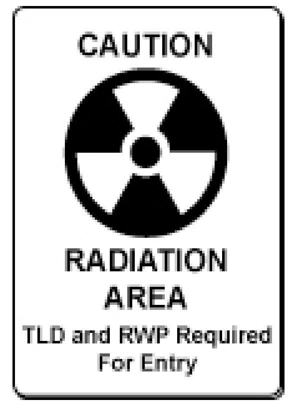
- Always follow ALARA practices.
- Obey policies on eating, drinking, smoking or chewing.
- Obey any posted, written or oral requirements, or radiological alarms.

Requirement for exit from RBA's:

- Personnel exiting a RBA which surrounds a contamination area, high contamination area, or airborne radioactivity area should, at a minimum, perform a hand and foot frisk.

Radiation Area

Radiation area means any area accessible to individuals in which radiation levels could result in an individual receiving a deep dose equivalent in excess of 5 mrem/hr but less than or equal to 100 mrem/hr. This is established based on dose rates at 30 cm from the source of radiation.



Posting Requirements

"CAUTION, RADIATION AREA"

"Personnel Dosimetry Required for Entry"

Minimum requirements for unescorted entry:

- Radiological Worker I Training.
- Personnel dosimetry.
- Worker's signature on the RWP, as applicable.

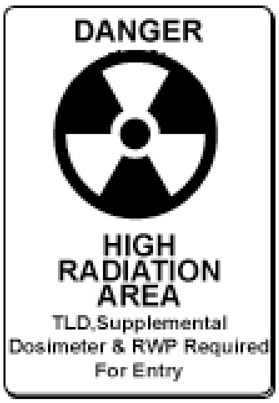
Requirements for working in radiation areas:

- Don't loiter in the area.
- Follow proper emergency response to abnormal situations.

Requirement for exit from radiation areas:

- Observe posted exit requirements.

High Radiation Area



High radiation area means any area accessible to individuals in which radiation levels could result in an individual receiving a deep dose equivalent in excess of 100 mrem/hr at 30 centimeters from the source but less than or equal to an absorbed dose of 500 rad/hr at 1 meter from the source of radiation.

Posting requirements:

" DANGER, HIGH RADIATION AREA"

" Personnel Dosimetry Required for Entry"

Requirement for working in high radiation areas:

• Entry into this area requires specialized training.

Very High Radiation Area

Very high radiation area means any area accessible to individuals in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rad/hr at 1 meter from the source of radiation.

Posting requirements:

**"GRAVE DANGER,
VERY HIGH RADIATION AREA"**

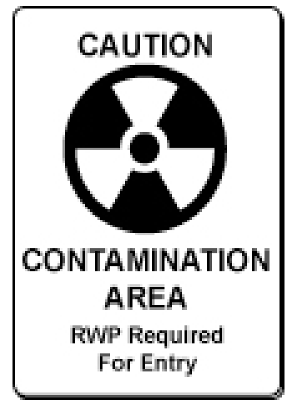
"SPECIAL CONTROLS REQUIRED FOR ENTRY"

Requirement for working in very high radiation areas:

• Entry into this area requires specialized training.

Contamination Area

Contamination areas are those areas where contamination levels are greater than 1 time but less than or equal to 100 times the specified DOE limits.



Posting requirement:

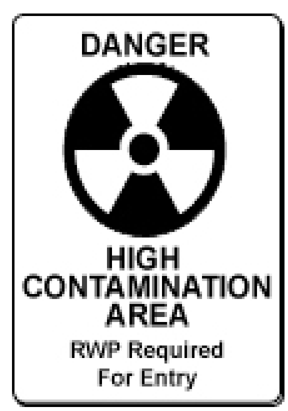
"CAUTION, CONTAMINATION AREA"

Requirements for working in contamination areas:

- Unescorted entry into this area requires specialized training.

High Contamination Area

High contamination areas are those areas where contamination levels are 100 times the specified DOE limits.



Posting requirements:

"DANGER, HIGH CONTAMINATION AREA"

"RWP REQUIRED FOR ENTRY"

Requirement for working in high contamination areas:

- Entry into this area requires specialized training.

Radioactive Material Area

Radioactive material area (RMA) is an area where radioactive materials are used, handled or stored. This posting is not be required when the radioactive materials are located inside Contamination or Airborne Radioactivity Areas.

Radioactive material may consist of equipment, components or materials which have been exposed to contamination or have been activated. Sealed or unsealed radioactive sources are also included. Radioactive materials may be stored in drums, boxes, etc., and will be marked appropriately.

Posting requirements:

"CAUTION, RADIOACTIVE MATERIAL"

The following posting will be used to designate equipment or components with actual or potential contamination:

"CAUTION, INTERNAL CONTAMINATION" or "CAUTION, POTENTIAL INTERNAL CONTAMINATION"

Minimum requirements for unescorted entry:

• Radiological Worker I training.

For entry into Radioactive Material Areas where whole body dose rates exceed 5 mrem/hour, the Radiation Area entry requirements will apply.
For entry into Radioactive Material Areas where removable contamination levels exceed the specified DOE limits, the Contamination Area entry requirements will apply.

• Requirements for working in RMAs
• Exit requirements.

Fixed Contamination Area

Fixed contamination areas may be an area or equipment that contains radioactive material that cannot be easily removed from surfaces by nondestructive means, such as wiping, brushing or laundering. Fixed contamination areas may be located outside of controlled areas.

Posting Requirement:

"CAUTION, FIXED CONTAMINATION"

Requirement for entry:

- Contact the Radiological Control Organization prior to entry.

Soil Contamination Area

Soil contamination areas contain surface soil or subsurface contamination levels that exceed the specified DOE limits. A Soil Contamination Area may be located outside an RBA.

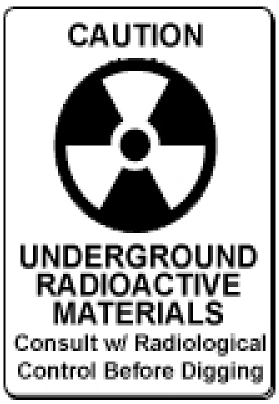
Posting requirement:

"CAUTION, SOIL CONTAMINATION"

Requirement for entry:

- Contact the Radiological Control Organization prior to entry.

Underground Radioactive Materials Area



Underground radioactive materials areas are established to indicate the presence of underground items that contain radioactive materials such as pipelines, radioactive cribs, covered ponds, inactive burial grounds and covered spills. Such areas may be outside of the Controlled Area.

Posting requirement:

"UNDERGROUND RADIOACTIVE MATERIALS"

Special instructions such as, "Consult with Radiological Control Organization before Digging" or "Subsurface Contamination Exists" may be included.

Requirements for entry:

- An Underground Radioactive Materials Area is exempt from the general entry and exit requirements if individual doses do not exceed 100 mrem in a year.
- Contact the Radiological Control Organization prior to entry.

Hot Spots

Hot spots are localized sources of radiation or radioactive material that are 5 times greater than the general area radiation levels and greater than 100 mrem per hour on contact. Generally, hot spots are found within equipment or piping.

Posting requirement:

"CAUTION, HOT SPOT"

Airborne radioactivity areas are those areas where the concentration of airborne radioactivity, above natural background, exceeds or is likely to exceed the specified DOE limits.

An airborne radioactivity area must be posted if the concentration of airborne contamination is higher than the natural background by at least 10 percent of the derived air concentration (DAC) during eight hours, or a peak concentration of 1 DAC.

The **derived air concentration (DAC)**. This is the concentration of a radioactive nuclide in the air (airborne radioactivity) that, if breathed in over the period of one year, would result in the Annual Limit on Intake (ALI) for that radioactive nuclide.

The DAC is obtained by dividing the ALI by the volume of air breathed by an "average" worker, at work, during one year (2400 m3).

The **annual limit of intake (ALI)** is the quantity of a single radionuclide which, if inhaled or ingested in one year, would cause radiation exposure equal to the annual dose limit (5 rem per year).

Posting requirements:

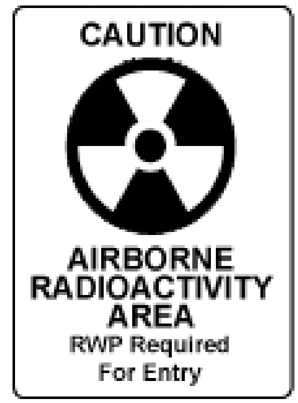
"CAUTION,
AIRBORNE RADIOACTIVITY AREA"

"RWP REQUIRED FOR ENTRY"

Requirement for working in airborne radioactivity areas:

• Entry into this area requires specialized training.

Airborne Radioactivity Area



Frisking Methods

General Requirements using a hand-held radioactive contamination survey instrument:

- Confirm the instrument is on, set to the proper scale and within the calibration date.
- Verify instrument response and perform source check.
- Ensure the audible function of the instrument is on and can be heard.
- Determine the instrument background.
- Survey hands before picking up the probe.
- Hold probe approximately ½" from the surface being surveyed for beta/gamma contamination and ¼" for alpha contamination.
- Move probe slowly over the surface, approximately 2" per second.
- If the count rate increases during frisking, pause for 5 to 10 seconds over the area to provide adequate time for instrument response.
- If contamination is indicated, remain in the area and notify the Radiological Control personnel.
- Minimize cross contamination (for example, put a glove on a contaminated hand) while waiting for the Radiological Control personnel to arrive.

AREA	DEFINITION	ENTRY REQUIREMENTS
Radiological Buffer Area.	The boundary area around other radiological areas that contain greater radiological hazards.	1) Radworker I or II training. 2) Personnel dosimetry.
Radiation Area.	More than 5 mrem/hr but less than or equal to 100 mrem/hr.	1) Radworker I or II training. 2) Signature on RWP. 3) Personnel dosimetry.
High Radiation Area.	More than 100 mrem/hr but less than or equal to 500 rad/hr.	1) Radworker I/High Rad or Radworker II training. 2) Signature on RWP. 3) Personnel and supplemental dosimetry. 4) Survey meter or dose rate indicating device.
Very High Radiation Area.	Greater than 500 rads per hour.	1) Special controls and training required for entry.
Contamination Area.	Any area where contamination levels are more than 1 but less than or equal to 100 times the specified DOE limits.	1) Radworker II training. 2) Personnel dosimetry. 3) Signature on RWP. 4) Protective clothing as required by the RWP.
High Contamination Area.	Any area where contamination levels are more than 100 times the specified DOE limits.	1) Same requirements as contamination areas. 2) Pre-job briefing.

AREA WORKING REQUIREMENTS	EXIT REQUIREMENTS
1) Always practice ALARA. 2) No eating, drinking, chewing or use of tobacco in the area.	1) Perform required frisk as posted. 2) Have all tools and equipment surveyed by Rad Control personnel prior to removal from the area.
1) Don't loiter in the area. 2) Follow proper emergency response to abnormal situations. 3) No eating, drinking, chewing or use of tobacco in the area.	1) Observe posted exit requirements.
1) Don't loiter in the area. 2) Follow proper emergency response to abnormal situations. 3) No eating, drinking, chewing or use of tobacco in the area.	1) Observe posted exit requirements.
1) Don't loiter in the area. 2) Follow proper emergency response to abnormal situations. 3) No eating, drinking, chewing or use of tobacco in the area.	1) Observe posted exit equirements.
1) Avoid unnecessary contact with contaminated surfaces. 2) Secure hoses and cables to prevent movement in and out of contaminated area. 3) Wrap or sleeve materials. 4) Place contaminated materials in appropriate containers when finished. 5) DO NOT TOUCH exposed skin. 6) Avoid stirring contamination. 7) No eating, drinking, chewing or use of tobacco in the area. 8) Exit immediately if wound occurs.	1) Exit only at step off pad (SOP). 2) Remove Protective Clothing prior to stepping on SOP. 3) Perform whole body frisk. If contamination is found: Stay in the area. Notify Rad Control Personnel. Minimize cross-contamination. 4) Have all tools and equipment surveyed by Rad Control prior to removal from the area.
1) Same requirements as contamination areas.	1) Same requirements as contamination areas.

AREA	DEFINITION (DOSE RATES IN THE AREA)	ENTRY REQUIREMENTS
Fixed Contamination Area.	An area or equipment with no removable contamination but fixed contamination levels are less than specified DOE limits.	1) None.
Soil Contamination Area.	An area where soil surface or subsurface contamination levels exceed the specified DOE limits.	1) Radworker I training (if surface soil is not disturbed) or Radworker II training. 2) Personnel dosimetry. 3) Signature on RWP. 4) Protective clothing.
Airborne Radioactivity Area.	An area where airborne radioactivity exceeds specified DOE limits.	1) Radworker II training. 2) Personnel dosimetry. 3) Signature on RWP. 4) Protective clothing as required by RWP. 5) Pre-job briefing.
Radioactive Materials Area.	An area where radioactive material is used, handled or stored.	1) Follow posted instructions. 2) No eating, drinking, chewing or use of tobacco in the area.
Underground Radioactive Materials Area.	An area that is established to indicate areas that may contain radioactive items underground.	None.

AREA WORKING REQUIREMENTS	EXIT REQUIREMENTS
1) Do not perform any activities that would disturb the fixed contamination surface without proper authorization.	1) None.
1) Avoid unnecessary contact with contaminated surfaces. 2) Secure hoses and cables to prevent movement in and out of contaminated area. 3) Wrap or sleeve materials. 4) Place contaminated materials in appropriate containers when finished. 5) DO NOT TOUCH exposed skin. 6) Avoid stirring contamination. 7) No eating, drinking, chewing or use of tobacco in the area. 8) Exit immediately if wound occurs	1) Exit only at step off pad (SOP) 2) Remove protective clothing prior to stepping on SOP. 3) Perform whole body frisk. If contamination found: Stay in the area. Notify Rad Control Personnel. Minimize cross-contamination.
1) Same requirements as contamination and soil contamination areas. 2) Exit immediately if any trouble occurs with respiratory equipment.	1) Same requirements as and soil contamination areas. 2) Remove respiratory protection equipment as directed and place in the proper receptacle.
1) Always practice ALARA.	1) Follow posted instructions.
1) Do not disturb the surface in these areas without proper authorization.	1) None.

Exercises

1.State the purpose of a radiological work permit (RWP).

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2. Check the information found on an RWP. (Check all those that apply.)

___ Expiration date.

___ Description of chemical hazards.

___ Hot work permit requirements.

___ Limiting radiological conditions which may void the permit.

___ Material safety data sheets.

___ Description of work.

___ Work area radiological conditions.

___ Dosimetry requirements.

___ Protective clothing.

___ Lock out/tag out permit number.

___ Authorizing signatures.

___ Fire systems check out.

___ Worker’s current dose.

3. Identify the worker's responsibilities in using Radiological Work Permits. Identify which of the following are worker responsibilities concerning RWPs. (Check all those that apply.)

___ Workers must read the RWP.

___ Workers must write the RWP.

___ Workers must comply with the RWP requirements.

___ Workers may substitute controls specified in the RWP.

___ Workers may continue to work in an area covered by an RWP even if instructions are not clear.

___ Workers must contact the radiological control personnel if RWP controls are not being followed.

4. Describe the colors and symbol used on radiological postings.

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____

5. State the radiological and disciplinary consequences of disregarding radiological postings, signs and labels.

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Exercises Continued

6. Match the definition to the area listed on the left.

(1) Any area accessible to individuals in which radiation levels could result in an individual receiving a deep dose equivalent in excess of 5 mrem/hr but less than or equal to 100 mrem/hr. This is established based on dose rates at 30 cm from the source of radiation.

(2) Areas accessible to individuals in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rad/hr at 1 meter from the source of radiation.

(3) Areas where the concentration of airborne radioactivity, above natural background, exceeds or is likely to exceed the specified DOE limits.

(4) Areas accessible to individuals in which radiation levels could result in an individual receiving a deep dose equivalent in excess of 100 mrem/hr at 30 centimeters from the source but less than or equal to an absorbed dose of 500 rad/hr at 1 meter from the source of radiation.

(5) Areas where contamination levels are greater than 1 but less than or equal to 100 times the specified DOE limits.

(6) Established within controlled areas to provide secondary boundaries to minimize the spread of radioactive contamination and to limit doses to general employees who have not been trained as Radiation Workers.

(7) An area where radioactive materials are used, handled or stored. This posting will not be required when radioactive materials are inside contamination or airborne radioactivity areas.

a. ___ High Radiation Area

b. ___ Contamination Area

c. ___ Radiological Buffer Area

d. ___ Radiation Area

e. ___ Airborne Radioactivity Area

f. ___ Very High Radiation Area

g. ___ Radioactive Materials Area

7. Identify the minimum requirements for entering, working and exiting a radiological buffer area.

8. Identify the minimum requirements for entering, working and exiting a radiation area.

9. State the personnel frisking requirements when exiting a radiological buffer area.

Notes

Chapter

7

High and Very High Radiation Areas

Learning Objectives

Given different radiological signs, IDENTIFY the requirements for each.

EO 1. DEFINE high radiation area and very high radiation area.

EO 2. IDENTIFY the signs and postings used for high radiation area and very high radiation areas.

EO 3. IDENTIFY site specific sources and locations that may produce high radiation areas and very high radiation areas.

EO 4. STATE the requirements for entering, working in and exiting high radiation areas and very high radiation areas.

EO 5. STATE the administrative and physical controls for access to high radiation areas and very high radiation areas.

EO 6. IDENTIFY the correct responses to emergencies and/or alarms within a high radiation area and a very high radiation area.

EO 7. STATE the DOE and site administration guidelines for control of emergency exposure.

Introduction To This Chapter

The High Radiation and Very High Radiation Area (HRA/VHRA) chapter familiarizes the participant with the course content, including entry, working in and exit requirements associated with these high radiation areas.

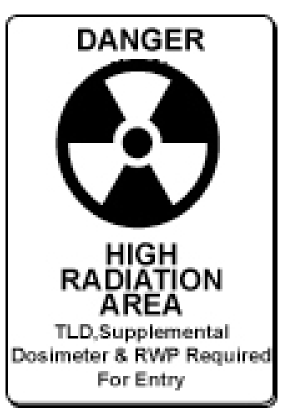
This lesson discusses information regarding the use of, working in and control of high radiation areas and materials emitting high radiation levels.

High Radiation Area

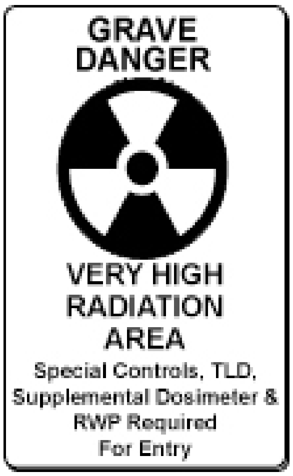
High Radiation Area: an area accessible to personnel in which radiation levels could result in a person receiving a dose equivalent in excess of 0.1 rem (100 mrem) but less than or equal to 500 rad in one hour at 30 centimeters (cm) from the radiation source. (Note that 30 cm equals about 1 ft.)

High Radiation Areas will be posted with the standard radiation symbol colored magenta (or black) on a yellow background, reading:

"DANGER, HIGH RADIATION AREA, TLD, Supplemental Dosimeter & RWP Required For Entry"



Very High Radiation Area



Very high radiation area: an area accessible to personnel in which radiation levels could result in a person receiving an absorbed dose in excess of 500 rad in one hour at 100 cm from a radiation source. (Note that 100 cm equals about 1 yard.)

Very high radiation areas will be posted with the standard radiation symbol colored magenta or (black) on a yellow background, reading:

**"GRAVE DANGER,
VERY HIGH RADIATION AREA,
Special Controls, TLD, Supplemental Dosimeter
& RWP Required For Entry"**

Entry Requirements

For High & Very High Radiation Areas

The requirements for entry into high and very high Radiation Areas include:

- Radiological Worker I training plus the high radiation and very high radiation area course or Radiological Worker II training.
- Worker signature on the appropriate Radiological Work Permit (RWP).
- Personal and supplemental dosimeter(s).
- Survey meter(s) or dose rate indicating device(s) must be available at the work area.
- Access points will be secured by control devices.
- A radiation survey prior to the first entry.
- Notification of operations personnel.

Working in High and Very High Radiation Areas

Additional requirements will be needed where dose rates are greater than 1 rem/hr. Examples include formal radiological review of non-routine or complex work, pre-job briefing, determination of worker's current dose, and radiological control coverage.

Always practice ALARA when working in high or very high radiation areas. In addition, never loiter. Know your job, perform it quickly and efficiently and exit upon completion of the identified task.

The DOE's objective is to maintain personnel radiation exposure well below regulatory dose limits. To accomplish this objective, challenging numerical Administrative Control Levels are established below the regulatory limits. These control levels are multi-tiered with increasing levels of authority required to approve higher Administrative Control Levels.

Administrative and physical access controls for high radiation and very high radiation areas are addressed in the DOE Radiological Control Manual. The methods used to control access may vary from facility to facility, depending upon the work environment and site work practices.

Administrative controls could include formal radiological reviews, RWPs, pre-job briefings, postings and procedures. Administrative control levels are set by the individual facilities and are generally well below regulatory dose limits. ACLs are determined by historical dose trends and anticipated future operations.

Exiting High and Very High Radiation Areas

There are site specific requirements for exiting High Radiation and Very High Radiation Areas. Write those site specific requirements here:

____
____
____
____

Interlocks

One or more of the following physical controls should be used for each entrance or access point into a High Radiation Area and are required at the entrance or access point if an individual could exceed a whole body dose of one rem in any one hour.

• A device that energizes a visible or audible alarm.

• Locked entry ways.

• Continuous direct or electronic surveillance.

Emergencies

Violation of a radiological boundary, posting or bypassing a physical access control is a serious issue, likely to result in damage to equipment or injury to personnel.

If unanticipated elevated radiation levels are indicated by an off scale dosimeter, radiological alarms or other indicators, you should stop work, alert others, immediately exit the area, and notify Radiological Control Personnel.

Controlling exposure to radiation during rescue and recovery actions is extremely complex. Multiple hazards and alternate methods are to be taken into

Emergencies (Continued)

account; prompt, sound judgement and flexibility of action are crucial to the success of any emergency actions. The risk of injury to those persons involved in the rescue and recovery activities should be minimized, to the extent practicable. However, the control of radiation exposures should be consistent with the immediate objectives of saving human life, recovering deceased victims,
and/or protection of health and property.

The type of response to these operations is generally left up to the officials in charge of the emergency situation. The official's judgment is guided by many variables which include determining the risk versus benefit of the action, as well as how to involve other personnel in the operation.

If the situation involves substantial personal risk, volunteers will be based on their age, experience and exposure. The emergency dose limits are:

- **10 rem** for protecting major property where the lower dose limit of 5 rem is not practicable.

- **25 rem** for saving a life or protection of large populations where the lower dose limit is not practicable.

- **Greater than 25 rem** for saving a life or protection of large populations - **only voluntary basis** to personnel fully aware of the risks involved.

Your facility may have site-specific emergency dose limits. Note these limits here:

____

____

____

Practice Questions

1.What are the minimum and maximum radiation levels at 30cm from a radiation source in which you would have to post a high radiation area?
How would this area be posted?

Minimum: ___________ Maximum: ____________

Posting: _____________________________________

____

____

2. What are the minimum and maximum radiation levels at 1 meter (100cm) from a radiation source in which you would have to post a very high radiation area? How would this area be posted?

Minimum: ___________ Maximum: ____________

Posting: _____________________________________

____

____

3.List site specific high and very high radiation areas.

____

____

____

____

4. What are the minimum requirements for entry into a high radiation area?

____

____

____

5. Label each of the following by placing administrative or physical control next to each of the following controls.

Formal radiological reviews: ________________

RWPs: ________________

Locked entry ways: ________________

Procedures: ________________

Alarms: ________________

Direct surveillance: ________________

6. What actions would you take if while working in a radiological area an ARM/RAM alarm sounded?

____

____

____

Notes

Chapter

8

Radiological Emergencies

Learning Objectives

Upon completion of this unit, the participant will be able to IDENTIFY radiological emergencies and alarms and the appropriate response to each.

The participant will be able to SELECT the correct response from a group of responses which verifies
his/her ability to:

EO 1. STATE the purpose and types of emergency alarms.

EO 2. IDENTIFY the correct responses to emergencies and/or alarms.

EO 3. STATE the possible consequences of disregarding radiological alarms.

EO 4. STATE the DOE and site administrative occupational emergency radiation dose guidelines.

Introduction To This Chapter

Various radiological monitoring systems are used to warn personnel if abnormal radiological conditions exist. It is very important that employees become familiar with these alarms to prevent unnecessary exposure to radiation and contamination.

Emergency Alarms and Responses

Devices that monitor for abnormal radiation dose rates and airborne contamination levels are placed in strategic locations throughout facilities. It is essential for the worker to be able to identify the equipment and alarms and respond appropriately to each.

Each DOE facility is equipped with radiation detection alarms which are designed to give audible and visible warnings if radiation or contamination levels go above a specified level. It is important that you understand the alarms in your facility, and know what action to take if an alarm sounds or if an emergency occurs.

The specific types of alarms vary from facility to facility. The following are descriptions of some of the common types of emergency radiation detection alarms.

RAM or ARM

The **remote area monitor (RAM)** may also be called the **area radiation monitor (ARM)**. This is a fixed location detector attached to a wall or other support. It monitors radiation levels in the area around the device. The alarm is activated if high radiation levels are detected. The alarm usually has a flashing red light, as well as a loud, fast sounding bell. If a RAM (ARM) goes off, evacuate the area and notify your supervisor and the Radiological Control Organization. Follow any additional site-specific procedures.

Continuous air monitor (CAM): A **CAM** measures airborne radioactivity levels. The instrument continuously samples the surrounding air. It collects airborne dust on a filter, and then measures any radioactivity on the filter. The CAM also has a flashing red light and a fast sounding bell. Most CAM's monitor for beta and gamma radiation, but there are some CAM's that can also detect alpha emitters in airborne dust. If a CAM goes off, evacuate the area and notify your supervisor and the Radiological Control Organization. Follow any additional site-specific procedures.

CAM

Criticality Alarm: A **criticality alarm** detects unusually high levels of gamma and/or neutron radiation to warn of a possible criticality accident. They are used at facilities where fissile material is present. These alarms usually sound a warbler siren as well as flashing lights. If a criticality alarm sounds, evacuate immediately. Follow the site specific evacuation procedures.

Criticality Alarm

Disregarding any of these radiological alarms may result in:

- Excessive personnel radiation dose
- Unnecessary spread of contamination
- Disciplinary action

Disregard For Radiological Alarms

Radiological Emergency Situations

Working in a radiological environment requires more precautionary measures than performing the same job in a non-radiological setting. If an emergency arises during radiological work, additional precautions may be necessary. Emergency situations can involve:

- Personnel injuries in areas controlled for radiological purposes.
- Situations that require immediate exit from an area controlled for radiological purposes.
- An accidental breach of a radioactive system or spill of radioactive material.

The first letters of each of these responses spell the word "SWIMS".

DOE uses the word "SWIMS" as a way to remember the correct response to an emergency situation in a radiologically controlled area:

- **S**top or secure the operation causing the spill.
- **W**arn others in the area, notify Radiological Control Personnel.
- **I**solate the spill area if possible.
- **M**inimize individual exposure and contamination.
- **S**ecure unfiltered ventilation (fans, open windows, etc.).

Rescue and Recovery Operations

In extremely rare cases, emergency exposure to high levels of radiation may be necessary to rescue personnel or protect major property.

Rescue and recovery operations that involve radiological hazards can be a very complex issue with regard to the control of personnel exposure. The type of response to these operations is generally left up to the official in charge of the emergency situation. The official's judgment is guided by many variables which include determining the risk versus the benefit of the action, as well as how to involve other personnel in the operation.

Rescue actions that might involve substantial personal risk shall be performed by volunteers. The use of volunteers will be based on their age, experience, and previous exposure.

Emergency Dose Guidelines

DOE emergency dose guidelines for rescue and recovery operations are as follows:

- **Protecting major property** where the lower dose limit of 5 rem is not practicable: **10 rem**.
- **Lifesaving or protection of large populations** where the lower dose limit is not practicable: **25 rem.**
- **Lifesaving or protection of large population - only on a voluntary basis** to personnel fully aware of risks involved: **greater than 25 rem.**

Your facility may have site-specific administrative emergency dose guidelines. Write those guidelines here:

___

___

___

Review Exercises

1. If you are working inside a contamination area and wearing anti-Cs, and you hear a radiation alarm, you should frisk before leaving the area.

True_____
False____

2. Radiation monitors are normally used to detect airborne radioactivity.

True_____
False____

3. Define the letters in the following acronym:

S ____

W ____

I ____

M ____

S ____

4. Which of the following requires immediate exit from a radiological area?

a. Off-scale Direct Reading Dosimeter (DRD)

b. A tear in the anti-C coveralls

c. A lost or damaged TLD

d. All of the above

Notes

Chapter

9

Radioactive Contamination Controls

Learning Objectives

Given different types of radioactive material, IDENTIFY the methods used to control the spread of contamination.

The participant will be able to SELECT the correct response from a group of responses which verifies his/her ability to:

EO 1. DEFINE fixed, removable and airborne contamination.

EO 2. STATE sources of radioactive contamination.

EO 3. STATE the appropriate response to a spill of radioactive material.

EO 4. IDENTIFY methods used to control radioactive contamination.

EO 5. IDENTIFY the proper use of protective clothing.

EO 6. IDENTIFY the purpose and use of personnel contamination monitors.

EO 7. IDENTIFY the normal methods used for decontamination.

EO 8. DEFINE Contamination, High Contamination, and Airborne Radioactivity Areas.

EO 9. IDENTIFY the requirements for entering, working in, and exiting a Contamination, High Contamination and Airborne Radioactivity Areas.

Introduction To This Chapter

This unit is designed to inform the worker of sources of radioactive contamination. It will also present methods used to control the spread of contamination.

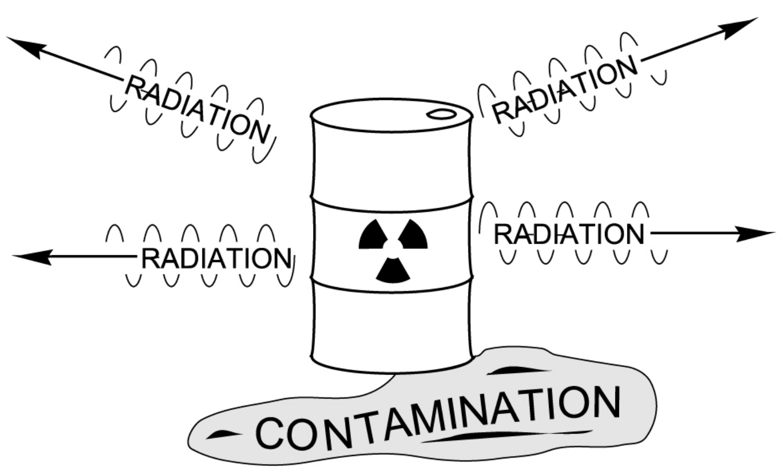
Contamination control is one of the most important aspects of radiological protection. Using proper contamination control practices will help ensure a safe working environment. It is important for all employees to recognize potential sources of contamination as well as to use appropriate contamination prevention methods.

Comparison of Radiation and Radioactive Contamination

Ionizing radiation: The energy (particles or rays) emitted from radioactive atoms that can cause ionization.

Radioactive contamination: Recall that radioactive material is material that contains radioactive atoms. Even when this radioactive material is properly contained, it may still emit radiation and be an external dose hazard, but it will not be a contamination hazard. When this radioactive material escapes its container, it is then referred to as radioactive contamination.

Radiation is energy; contamination is a material.



Radiation is energy.

Contamination is a material.

Types of Contamination

Radioactive contamination can be fixed, removable or airborne.

- **Fixed contamination** is contamination that cannot be readily removed from surfaces. It cannot be removed by casual contact. It may be released when the surface is disturbed by buffing, grinding, using volatile liquids for cleaning, etc. Over time it may "weep," leach or otherwise become loose or transferable.

- **Removable/transferable contamination** is contamination that can readily be removed from surfaces. It may be transferred by casual contact, wiping, brushing or washing. Air movement across removable/transferable contamination could cause the contamination to become airborne.

- **Airborne contamination** is contamination suspended in air.

Sources of Radioactive Contamination

Regardless of the precautions taken, radioactive material will sometimes escape and contaminate an area. The following are some sources of radioactive contamination:

- Sloppy work practices, that lead to cross-contamination of tools, equipment or workers. Examples include:

- Opening radioactive systems without proper controls.

- Poor housekeeping in contaminated areas.

- Excessive motion or movement in areas of higher contamination.

- Leaks or breaks in radioactive systems.

- Small, sometimes microscopic pieces of radioactive material that are highly radioactive may escape. These pieces are known as “hot particles.” Hot particles may be present when contaminated systems are opened. These particles may also be present when machining, cutting, or grinding is performed on highly radioactive materials. They can cause a high, localized radiation dose in a short period of time if they remain in contact with skin/tissue.

- Airborne contamination depositing on surfaces.

- Leaks or tears in radiological containers such as barrels, plastic bags or boxes.

Indicators of Possible Area Contamination

Workers need to be aware of potential radiological problems. Here are some examples of potential radiological problems.

• Leaks, spills, standing water

• Damaged radiological containers

Employee response to a spill of radioactive material.

Each of the examples listed above may be considered a spill of radioactive material. Here is the minimum response to a spill of radioactive material.

• Stop or secure the operation causing the spill.

• Warn others in the area.

• Isolate the area.

• Minimize exposure to radiation and contamination.

• Secure unfiltered ventilation.

• Notify Radiological Control personnel.

Contamination Control Methods

Every possible effort should be made to confine the spread of radioactive materials to the smallest area possible. By controlling contamination, the potential for internal exposure and personnel contamination can be limited. Here are some methods used to control the spread of radioactive contamination.

There are three catagories of contamination control methods:

- Preventive methods (maintenance and good work practices).
- Engineering control methods (ventilation and containment).
- Personnel protective measures (protective clothing and respiratory protection equipment).

Preventive Methods

A sound preventative maintenance program can prevent many radioactive material releases. Here are some preventative methods.

- Identify and repair leaks before they become a serious problem.
- Establish adequate work controls before starting jobs.
- Discuss measures that will help reduce or prevent contamination spread. This can be done during pre-job briefs.
- Change out gloves or protective gear as necessary to prevent cross-contamination of equipment.

Preventive methods continued on the next page.

Preventive Methods (Continued)

- Stage areas to prevent contamination spread from work activities.

- Cover piping and equipment below a work area to prevent dripping contamination onto cleaner areas. Another example would be covering/taping tools or equipment used during the job to minimize decontamination after the job (i.e., taping up a screwdriver before use).

- Use good work practices such as good housekeeping and cleaning up after jobs. "Good Housekeeping" is the prime factor in an effective contamination control program. It involves the interaction of all groups within the facility. Each individual should be dedicated to keeping "his house clean" to control the spread of contamination.

- Control and minimize all material taken into or out of contaminated areas.

- Be alert for potential violations to the basic principle of contamination control; such as use of improper contamination control methods, bad work practices, basic rule or procedure violations, radioactive material releases or liquid spills.

- Radiological workers should always ensure that the proper procedures to avoid the spread of contamination are followed or implemented.

Engineering Control Methods

Engineering control refers to the use of ventilation systems, enclosures, piping, filtration devices, shielding, robotics and automation to control radiation exposures.

Ventilation

- Ventilation is designed to maintain airflow from areas of least contamination to areas of most contamination (e.g., clean to contaminated to highly contaminated areas). A slight negative pressure is maintained on buildings/rooms where potential contamination exists.
- High efficiency particulate air (HEPA) filters are used to remove radioactive particles from the air.

Containment

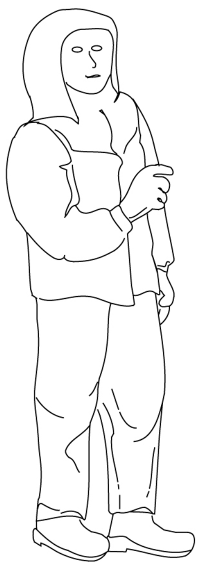
- Containment generally means using vessels, pipes, cells, glovebags, gloveboxes, tents, huts, plastic coverings, etc. to control contamination by containing it.

Personnel Protective Measures

If engineering methods are not adequate, then personnel protective measures such as protective clothing and respiratory equipment will be used.

Personnel protective measures include the use of protective clothing, and the use of respiratory protection equipment.

Protective Clothing



Protective clothing is required to enter areas containing contamination and airborne radioactivity levels above specified limits to prevent contamination of personnel skin and clothing. The degree of clothing required is dependent on the work area radiological conditions and the nature of the job.

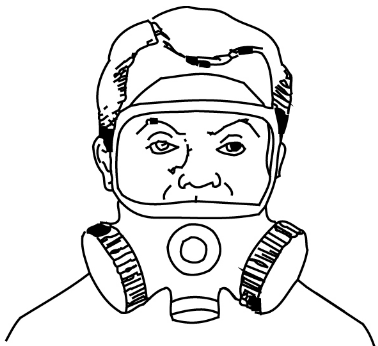
- Personal effects such as watches, rings, jewelry, etc., should not be worn.
- Full protective clothing generally consists of coveralls, cotton liners, gloves, shoe covers, rubber overshoes, and a hood.
- NOTE: Cotton glove liners may be worn inside of standard gloves for comfort, but should not be worn alone or considered protection against contamination.

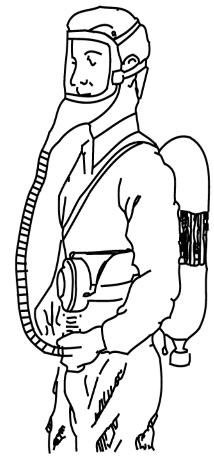
Proper Use of Protective Clothing

- Inspect all protective clothing for rips, tears, holes, etc., prior to use. If you find damaged clothing, discard of it properly.
- Supplemental dosimeters should be worn as prescribed by the Radiological Control Organization.
- After donning protective clothing, proceed directly from the dress-out area to the work area.
- Avoid getting coveralls wet. Wet coveralls provide a means for contamination to reach the skin/clothing.
- Contact Radiological Control personnel if clothing becomes ripped, torn, etc.

Respiratory Protection Equipment

Respiratory protection equipment is used to prevent the inhalation of radioactive materials. The training course which you are now taking does not qualify a worker to wear respiratory protection.

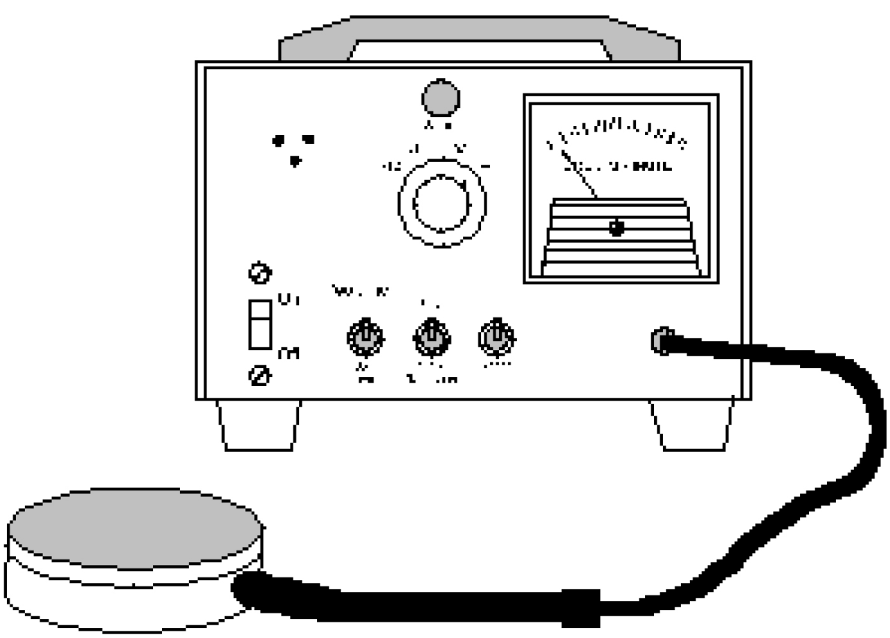




Contamination Monitoring Equipment

Contamination monitoring equipment is used to detect radioactive contamination on personnel and equipment.

Contamination monitoring is done with a monitor or frisker such as the one pictured below.



Frisking Procedure

1. Verify the instrument is in service, set to the proper scale and the audio can be heard.

2. Note background count rate at frisking station.

3. Frisk hands before picking up the probe.

4. Hold probe approximately ½” from surface being surveyed for beta/gamma and ¼” for alpha.

5. Move probe slowly over surface, about 2” per second.

6. Proceed to perform frisk as follows, if appropriate.

- Head. (Pause at mouth & nose for about 5 seconds.)
- Neck and shoulders.
- Arms (pause at each elbow).
- Chest and abdomen.
- Back, hips and seat of pants.
- Legs (pause at knee).
- Shoe tops.
- Shoe bottoms (pause at sole and heal).

7. Personnel and supplemental dosimetry.

8. The whole body survey should take at least 2-3 minutes per survey instrument.

9. Carefully return the probe to holder. The probe should be placed on the side or face up to allow the next person to monitor.

10. If the count rate increases during frisking, pause for 5-10 seconds over the area to provide adequate time for instrument response.

11. Take appropriate actions if contamination is indicated; remain in the area and notify Radiological Control personnel. Minimize cross-contamination (such as putting a glove on a contaminated hand).

Decontamination

Decontamination is the removal of radioactive materials from locations where it is not wanted. If the presence of removable contamination is discovered, decontamination is a valuable means of control.

Personnel decontamination is normally accomplished using mild soap and lukewarm water.

Material decontamination is the removal of radioactive materials from tools, equipment, floors and other surfaces in the work area.

In some situations, decontamination is not possible.

Economical conditions: Cost of time and labor to decontaminate the location outweigh the hazards of the contamination present.

Radiological conditions: Radiation dose rates or other radiological conditions present hazards which far exceed the benefits of decontamination.

NOTE: Decontamination should be performed by qualified personnel under the direction of the Radiological Control Organization.

Types of Contamination Areas

There are three types of contamination areas:

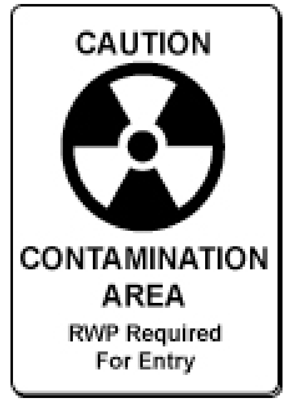
1. Contamination area.

2. High contamination area.

3. Airborne radioactivity area.

Contamination Area

A **contamination area** is an area where contamination levels are greater than specified limits.

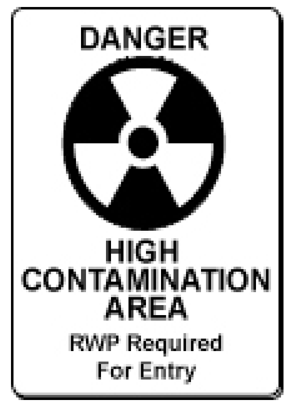


Posting requirements:

"CAUTION, CONTAMINATION AREA"

High Contamination Area

A **high contamination area** is an area where contamination levels are 100 times greater than the Contamination Area limits.

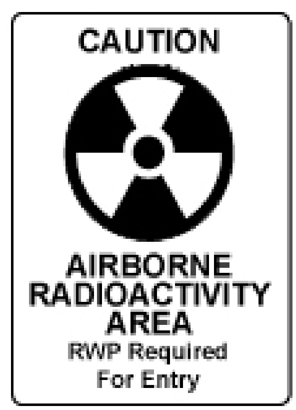


Posting requirements:

"DANGER, HIGH CONTAMINATION AREA, RWP REQUIRED FOR ENTRY"

Airborne Radioactivity Area

An **airborne radioactivity area** is an area where the concentration of airborne radioactivity, above natural background, exceeds or is likely to exceed the specified DOE limits



PostingRequirements:

"CAUTION. AIRBORNE RADIOACTIVITY AREA, RWP REQUIRED FOR ENTRY"

Requirements For Entering

The following are required for **entering contamination areas, high contamination areas** and **airborne radioactivity areas:**

- Radiological Worker II Training.
- Personnel dosimetry, as appropriate.
- Protective clothing and respiratory protection as specified in the RWP.
- Worker's signature on the RWP, as applicable.
- Pre-job briefings as applicable.

Requirements For Working

The following practices are required for working into **contamination areas, high contamination areas** and **airborne radioactivity areas:**

- Avoid unnecessary contact with contaminated surfaces.
- Secure equipment (lines, hoses, cables, etc.,) to prevent them from crossing in and out of contamination area.
- When possible, wrap or sleeve materials, equipment and hoses.
- Place contaminated materials in appropriate containers when finished.
- DO NOT touch exposed skin surfaces. Highly contaminated material left on the skin for an extended period of time can cause a significant localized dose to the skin.
- Avoid stirring contamination, it could become airborne.
- Do not smoke, eat drink or chew.
- Exit immediately if a wound occurs.

Exit Requirements

The following are required for exit from contamination areas, high contamination areas and airborne radioactivity areas:

- Exit only at the step-off pad.
- Use proper techniques to remove protective clothing.
- Frisk or be frisked for contamination when entering an uncontaminated area. If personal contamination is found, stay in the area, notify the Radiological Control Technician and minimize the potential for cross contamination.
- Survey all tools and equipment prior to removal from the area.
- Observe RWP and control point guidelines.

Practice Questions

1. Draw lines to match the term with the definition.

Contamination that can be transferred by casual contact.	Fixed contamination.
Contamination suspended in air.	Removable contamination.
Contamination that cannot be readily removed from surfaces.	Airborne contamination.

2. Which of the following are sources of radioactive contamination (check all that apply)?

__ Poor housekeeping.

__ Receiving an x ray.

__ Excessive movement in contamination areas.

__ Leaks or breaks in radioactive systems.

__ Over exposure to sunlight.

3. The first action an employee should take for a spill of radioactive material is ___________________.

4. The three general methods to control radioactive contamination are ______________________________, ____, and ____.

Practice Questions (Continued)

5.Protective clothing must be ________________ prior to use.

6. While frisking with a beta-gamma frisker the probe should be held __________ inch or less from the surface and moved at a rate of not greater than _________ inches per second.

7. The alpha probe must be held within _______ inch from the surface.

8. Personnel decontamination is normally accomplished by:

A. Scrubbing with a wire brush.
B. Acidic based chemicals.
C. Mild soap and lukewarm water.
D. Mild soap and hot water.

9. An area where contamination levels are 100 greater than the Contamination Area limits is called a/an:

A. High Radiation Area.
B. Very High Radiation Area.
C. Airborne Radioactivity Area.
D. High Contamination Area.

10. In order to enter a Contamination Area a worker must receive which of the following training?

A. GERT.
B. Radiological Worker I.
C. Radiological Worker II.
D. HAZWOPER.

Glossary

GL

Glossary

Radiological Terms Abbreviations and Acronyms

Abnormal situation: An unplanned event or condition what adversely affects, potentially affects or indicates degradation in the safety, security, environmental or health protection performance or operation of a facility.

Activation: The process of producing a radioactive material by bombarding a nonradioactive material with neutrons, protons or other nuclear particles.

Acute dose: A large radiation dose received over a short period of time.

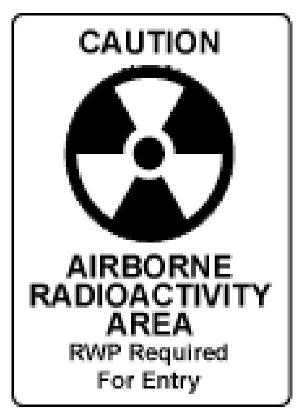
Acute effect: A health effect which occurs soon after a relatively high dose of ionizing radiation. For example, changes in blood cells may occur after an acute dose of 10 to 15 rem. Radiation sickness may occur after an acute dose of 100 rem.

Acute radiation syndrome: A condition which results from a very large acute dose of ionizing radiation. Symptoms include hair loss, nausea, vomiting and spasms.

Administrative control level: A radiation dose level which is lower (more protective) than the dose limit established by DOE regulations. The purpose is to maintain exposure below the regulatory limits. There are two types of administrative control levels: A **DOE administrative control level** is set by DOE. A **facility administrative control level** is set by the facility. [See the **Summary of Radiation Dose Limits and Control Levels** under **Radiation dose limit** later in this Glossary.]

Airborne contamination: Radioactive material that is in the air. This includes radioactive gases and vapors, or radioactive particulates such as dusts, powders, mists or sprays.

Airborne radioactivity: Another name for airborne contamination.



Airborne radioactivity area: An area designated as having a concentration of airborne contamination which is higher than the natural background by at least 10 percent of the derived air concentration (DAC) during eight hours, or a peak concentration of 1 DAC.

ALARA: **A**s **L**ow **A**s **R**easonably **A**chievable. The concept of keeping exposures as low reasonably achievable. **ALARA** is not a dose limit, but an ongoing process to keep exposures as low as reasonably achievable.

ALARA program: The program which the contractor is required to maintain in order to assure that radiation doses are not just below the required levels, but even lower: as low as reasonably achievable. The ALARA Program includes an ALARA committee, and ALARA goals. The ALARA Program is a fundamental requirement of every radiological control program.

ALARA committee: The ALARA Committee shall include managers, workers, technical support personnel and representatives of the radiological control organization. The ALARA Committee: 1) Makes recommendations to management to improve progress toward minimizing radiation exposure and releases of radioactive material; 2) Evaluates construction and design plans, major modifications of work activities, and plans for waste and release minimization;
3) Receives and reviews audits of the Radiological Control Program; and 4) Reviews the overall conduct of the Radiological Control Program.

Alpha particle (α): A charged particle emitted at a very high velocity from the nucleus of a radioactive atom. An alpha particle consists of two protons and two neutrons. It has a mass of four atomic mass units and a positive charge of two (+2).

Alpha radiation (α): Ionizing radiation in the form of alpha particles. Alpha radiation is an internal radiation hazard. Because alpha radiation cannot penetrate the dead layer of skin cells on the surface of the body, it is not an external radiation hazard. Alpha radiation has a range in air of only one or two inches because it quickly deposits its energy as it collides with air molecules.

Annual limit of intake (ALI): The quantity of a single radionuclide which, if inhaled or ingested in one year, would cause radiation exposure equal to the annual dose limit (5 rem per year).

Anti-C clothing (anti-contamination clothing): Protective clothing, usually made of cotton or other fabric in a canary yellow color, and intended to reduce or prevent contact with radioactive contamination.

Area radiation monitor: A device mounted in a radiation area which measures the level of ionizing radiation and which sounds an alarm if abnormal levels occur.

Atom: The smallest piece or unit of an element. An atom consists of a nucleus surrounded by an electron cloud. The nucleus contains one or more protons. The nucleus of each atom except normal hydrogen also has one or more neutrons.

Background radiation: Radiation from naturally occurring sources including: 1) Cosmic radiation from outer space; 2) Radiation from uranium and other naturally occurring elements in the earth's crust (terrestrial radiation); 3) Radon gas in the atmosphere; and 4) Radioactive elements incorporated within our own bodies (internal radiation).

Becquerel (Bq): A measurement unit for the activity of radioactive material. One Becquerel is that quantity of radioactive material in which one atom disintegrates per second. 37 billion Bq = 1 Curie.

Beta particle (β): A charge particle emitted at great velocity from the nucleus of a radioactive atom. A beta particle is the same size and weight as an electron, and usually has a charge of minus one (-1). Beta particles are sometimes referred to as fast moving electrons, although they come from the nucleus, not from the atom's electron cloud. A beta particle with a positive charge (+1) is called a **positron**.

Beta radiation (β): Ionizing radiation made up of beta particles. Beta radiation is an internal hazard if radioactive material which emits beta radiation is absorbed into the body. Beta radiation can penetrate the first few layers of skin cells. This makes it an external hazard to the skin and eyes. Beta radiation has a range of several inches in air.

Bioassay: A measurement of the amount of radioactive material deposited in the human body, or excreted from the body. Examples of bioassays are whole-body counting, organ counting, urine analysis, fecal analysis and analysis of other biological specimens.

Biological effect: An effect that may occur in a cell as the result of exposure to ionizing radiation. Generally the effect is caused by ionization of atoms in biological molecules within the cell. Biological effects include both acute effects and chronic effects. Biological effects are also called "health effects."

Calibration: The process of adjusting a measuring or monitoring instrument by comparing its reading to a known standard.

Carcinogen: A chemical or physical agent which can cause cancer. Ionizing radiation is known to cause certain kinds of cancer. Ionizing radiation is a carcinogen.

Cell: The basic unit of all living organisms.

Cell membrane: The surface or wall that surrounds and encloses a cell.

Cell nucleus: A structure inside of a cell containing the cell's chromosomes.

Chromosome: A structure within the cell's nucleus that contains the cell's genetic material (DNA), and which transmits genetic information when the cell divides to form two new cells.

Chronic dose: A radiation dose received over a long period of time.

Containment device: A barrier such as a glovebag, glovebox or tent used to inhibit the release of radioactive material from a specific location.

Contamination area (CA): An area where the amount of radioactive contamination is enough to create radiation levels greater than the values given in Table 2-2 of the DOE **Radiological Control Manual** (DOE N-5480.6), but less than or equal to 100 times those values. Note that there are different values for different radionuclide contaminants. Table 2.2 is reproduced in Appendix C. Note that if the levels are greater than 100 times the Table 2.2 values, then it is a High Contamination Area.

Contamination survey: The use of swipes, smears, or direct instrument surveys to identify and measure radioactive material on people, equipment, surfaces or areas.

Continuous air monitor (CAM): An instrument that continuously measures the levels of airborne radioactive material in an area on a “real time” basis, and is designed to sound an alarm if the concentration of radioactive material reaches a preset level.

Controlled area: An area, room, building, etc. to which access is controlled in order to protect personnel from exposure to radiation of contamination from radioactive materials.

Cosmic radiation: Cosmic radiation which reaches the earth from outer space. Most cosmic radiation is absorbed in the atmosphere, but some reaches the surface of the earth where it is part of the natural background radiation to which we are all exposed. Cosmic radiation exposure is greater at higher altitudes.

Counts per minute (cpm): A unit for measuring radioactivity. Counts per minute is the response of a survey meter or other measuring device. Counts per minute (cpm) is not usually the same thing as disintegrations per minute (dpm), because the meter is generally less than 100% efficient, which means that it does not count every disintegration. cpm/efficiency = dpm.

Critical mass: The smallest amount (mass) of fissionable material that will support a self-sustaining nuclear chain reaction under specified conditions.

Curie (Ci): A unit of measurement for the activity of radioactive material. 1 Ci = 37 billion disintegrations per second. 1 Ci = 37 billion Bq. 1 Ci = 2,200 billion dpm.

Declared pregnant worker: A woman employee who has voluntarily informed her employer, in writing, of her pregnancy and the estimated date of conception.

Decontamination: The process of removing radioactive material from people, equipment, surfaces and areas.

Derived air concentration (DAC): The concentration of a radioactive nuclide in the air (airborne radioactivity) that, if breathed in over the period of one year, would result the Annual Limit on Intake (ALI) for that radioactive nuclide being exceeded. The DAC is obtained by dividing the ALI by the volume of air breathed by an "average" worker, at work, during one year (2400 m^3).

Distance: A method of reducing exposure to ionizing radiation by increasing the distance between the radiation source and the worker.

Disintegrations per minute (dpm): A unit for measuring the activity of radioactive material. 60 dpm = 1 disintegration per second, or 1 Bq. Disintegrations per minute equals counts per minute divided by the efficiency of the survey meter.

DOE: The United States Department of Energy.

DOE activity: An activity taken for or by DOE that has the potential to result in the occupational exposure of an individual to radiation or radioactive material. The activity may be, but is not limited to, design, construction, operation, decontamination or decommissioning. To the extent appropriate, the activity may involve a single DOE facility or operation or a combination of facilities and operations, possibly including an entire site.

Dose (radiation dose): In common speech, radiation dose refers to the amount of mrems or rems of ionizing radiation you receive. Note that this is technically incorrect, since mrem and rem measure **dose equivalent**, not dose. However, it is simpler to just say "dose" instead of "dose equivalent."

Technically, radiation dose is the amount of energy deposited in body tissue due to radiation exposure. Radiation dose, in this sense, is measured in rads and millirads, or in grays. To convert from dose (rads, millirads, grays) to dose equivalent (rems, millirems, sieverts), multiply by the quality factor for the particular type of radiation.

There are several different "dose" terms used to describe the interaction of ionizing radiation with tissue and to describe the radiation exposure of individuals and populations. For more information see Appendix A.

Dose assessment: The process of determining the radiation dose received by a person or a community through the use of monitoring data, bioassay results, estimates based on exposure scenarios, pathway analysis, etc.

Dose equivalent: A measure of the biological effect of radiation that is absorbed by the body. Dose equivalent is measured in mrem and rem, or in sieverts. Mathematically, dose equivalent in rem or millirem is calculated by multiplying the dose in rads or millirads by a "quality factor" which takes into account the biological effectiveness of the type of ionizing radiation involved. (Dose equivalent in sieverts is calculated by multiplying the dose in grays by the appropriate quality factor.)

Dose rate: The rate at which a person receives a radiation dose. Usually we are referring to the "dose equivalent" in mrem, but it is common practice to simply say "dose rate" instead of "dose equivalent rate." For example, the dose rate in a certain situation might be 100 mrem per hour. This means that if a person spent one hour under these conditions, he or she would receive a dose of 100 mrem. In one-half hour they would receive 50 mrem, etc.

Embryo/fetus: The developing human organism from the time of conception to the time of birth.

Electron: A negatively charged particle which orbits the nucleus of an atom.

Electron cloud: Another way of describing the "orbits" of the electrons around the nucleus of an atom.

Engineering controls: The control of radiation exposure and radioactive contamination through the use of ventilation systems, enclosures, piping, filtration devices, shielding, etc. This is in contrast to relying solely on personal protective equipment or good work practices to control exposures.

Entrance or access points: Any location through which a person could gain access to a radiologically controlled area. This includes entry or exit portals of sufficient size to permit human entry.

Extremities: The hands and forearms below the elbow, and the feet and lower legs below the knees.

External contamination: Radioactive contamination (materials) on the body or clothing, but not inside the body.

External dosimetry: Devices such as film badges, TLD's and pocket self-reading dosimeters worn on the body to measure exposure to external sources of radiation.

External exposure: Exposure to radiation from sources located outside of the body.

Film badge: A personnel monitoring device which used photographic film inside a badge to measure radiation exposure. When the film is developed, the darker the film, the greater the exposure.

Finger ring: A piece of thermoluminescent material encased in a ring that is worn on the finger as a way to monitor for radiation exposure to the hand (extremities).

Fixed contamination: Radioactive material that cannot be removed readily from surfaces by casual contact, wiping, brushing or washing.

Fixed contamination area: An area which contains no removable contamination, but contains fixed contamination exceeding specified limits.

Frisk, frisking: The process of monitoring a person to determine whether they are contaminated with radioactive material. Frisking can be performed using a hand-held survey instrument, an automated monitoring device such as PCM, or by Radiological Control Personnel.

Gamma radiation (γ): Ionizing radiation in the form of gamma rays. Gamma radiation has high penetrating power, so that it is an external radiation hazard. If radioactive material that emits gamma radiation gets into the body, then the gamma radiation is also an internal hazard.

Gamma ray (γ): A ray of pure energy emitted from the nucleus of certain radioactive atoms.

Gene: A small section of DNA containing the genetic information for a particular trait.

Genetic effect: A biological effect on the genetic material (DNA) in a cell. This effect causes changes in other cells produced by that cell. This is also called a mutation. Note that a genetic effect can occur in any cell of the body. If the effect occurs in a cell involved in human reproduction (a sperm or an egg), it is called a **heritable effect**. This might lead to an adverse reproductive effect. If a genetic effect occurs in a cell which is not involved in human reproduction, it is called a **somatic effect**. This might lead to cancer.

Gestation period: The time from conception to birth, approximately nine months.

Gray (Gy): A new unit for measuring absorbed radiation dose. 1 gy = 100 rad.

HEPA filter (high efficiency particulate air filter): A filter that can remove tiny particulates from the air. HEPA filters are used in respirators and in ventilation filtration systems. The technical specification for a HEPA filter is that it is capable of removing 99.97% of particulates having an average diameter of 0.3 micrometers (millionths of a meter).

Heritable effect: A genetic effect that occurs in the reproductive cells (sperm or eggs) and is inherited from a parent or passed on to a child.

High contamination area: An area where the contamination levels are greater than 100 times the values given in Table 2-2 of the DOE **Radiological Control Manual** (DOE N-5480.6). Note that there are different values for different radionuclide contaminants. Table 2.2 is reproduced in Appendix C. See also the definition of Contamination Area.

High radiation area: An area where radiation dose rates are greater than 100 mrem per hour, but less than 500 rad per hour.

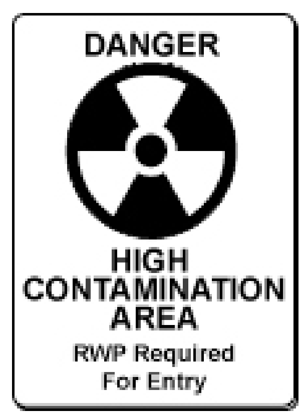
Hot particle: A very small piece of nuclear fuel or radioactive material corrosion product which has a high level of radioactivity as the result of nuclear fission or neutron activation. The word “particle” here refers to a piece of material in the form of a dust or powder. Don’t confuse this with the use of the word “particle” to describe the individual parts of an atom (proton, neutron and electron) or the types of particulate radiation (alpha, beta and neutron).

Hot spot: A localized source or radiation caused by the presence of radioactive material sufficient to cause radiation exposure at least 5 times higher than the surrounding area, and at a dose rate of at least 100 mrem per hour.

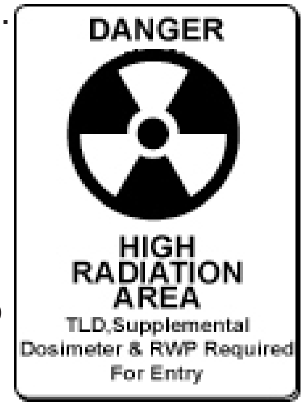
Internal contamination: Radioactive material that has gotten into the body by one or more routes of entry (inhalation, ingestion, skin absorption or entry through a wound.

Internal exposure: Exposure to radiation from radioactive materials which have been inhaled, ingested, absorbed through the skin or have entered through a wound.

Internal radiation: Radiation from radioactive materials which have been inhaled, ingested, absorbed through the skin or have entered through a wound.



Ion: An atom which has lost or gained one or more electrons. An ion is not electrically neutral. If it has lost an electron, then it has less negative charge than positive charge, which means it has a net positive electric charge. On the other hand, if it has gained an electron, then it has a net negative charge.



Ionization: A process by which one or more electrons is removed from an atom. Radiation that has enough energy to cause ionization is called **ionizing radiation**.

Ionizing radiation: Energy, in the form of a wave or a fast moving particle, which is capable of ionizing an atom.

Isotopes: Atoms which have the same number of protons (so they are the same element), but have a different number of neutrons.

Low level radioactive waste: Radioactive waste that is not classified as high-level waste, transuranic waste, spent nuclear fuel or by-product material.

Millirem (mrem): One one-thousandth (1/1000) of a rem. A unit for measuring the dose equivalent of radiation absorbed by tissue.

Mixed Waste: Waste containing both radioactive and hazardous chemical components.

Neutron: One of the basic particles found in the nucleus of an atom. It is called “neutron” because it is electrically neutral (has no electrical charge)

Neutron radiation: Ionizing radiation consisting of neutron particles produced during the fission process in a nuclear reactor or particle accelerator. Neutron radiation has a high penetrating ability and require shielding material that has a high hydrogen content, such as plastic or water.

Non-ionizing radiation: Radiation such as radio waves, micro waves, radar, infra red, visible light, or ultra violet that does not have enough energy to ionize atoms.

Nuclear criticality: An event in which radioactive material undergoes a self-sustaining nuclear chain reaction.

Nuclear Regulatory Commission (NRC): Federal agency that regulates civilian nuclear power plants.

Nucleus: **1**. The core of an atom, where protons and neutrons are found. If the nucleus is unstable, then the atom is radioactive. The nucleus of a radioactive atom is the source of ionizing radiation in the form of alpha, beta or neutron particles, or gamma rays. **-OR- 2**. The part of a living cell that contains the genetic material DNA.

Occupational dose: The amount of an individual's dose due to exposure to ionizing radiation (both external and internal) as a result of that individual's work assignment. By definition, occupational dose does not include planned special exposures, exposure received as a medical patient, background radiation, or voluntary participation in medical research programs.

Personal contamination monitor: A monitor that detects radiation emitted from contamination on the body.

Personal monitoring: A systematic and periodic estimate of the radiation dose received by personnel during working hours. Also, the monitoring of personnel, their excretions, their skin or any part of their clothing to determine the amount of radioactive contamination present.

Personal protective equipment: Any safety equipment worn by the worker and designed to protect the worker against hazards. Examples include respirators, gloves, protective clothing (anti-c's), etc.

Planned special exposure: A pre-planned, infrequent exposure to radiation which is separate from, and in addition to the annual dose limits.

Prenatal radiation exposure: The exposure of an embryo/fetus to ionizing radiation.

Pocket alarm dose indicator (PADI): A small personal monitoring device with a digital display and an audible alarm.

Primary dosimeter: A dosimeter (often a TLD) worn on the body and used to obtain the formal legal record of whole body radiation dose.

Protective clothing: Clothing provided to personnel to minimize the potential for skin contamination or contamination of other personal or company issued clothing worn under the protective clothing. Protective clothing is also referred to as **anti-contamination clothing**, **anti-c's** or **PC's**.

Proton: A positively charged particle located in the nucleus of the atom.

Public: Any individual or group of persons who is not occupationally exposed to radiation or radioactive material. A person is not considered a "member of the public" during any period in which the person receives an occupational dose.

Quality factor (QF): A number indicating the biological effect of a particular type of ionizing radiation. When radiation exposure (rads, millirads, grays) is multiplied by the quality factor, the product is the dose equivalent (rem, mrem, sievert).

Radiation: Energy that radiates out from a source. This includes both ionizing and non-ionizing radiation. Note that is this manual, "radiation" means "ionizing radiation" unless the context clearly indicates otherwise.

Radiation absorbed dose (rad): A measure of the amount of energy deposited in tissue when it is exposed to ionizing radiation.

Radiation area (RA): An area where dose rates are greater than 5 mrem per hour but less than 100 mrem per hour.

Radiation dose limit: A limit set by DOE regulations for the maximum radiation exposure that a person may receive under routine conditions. Both DOE and the facility contractors also set administrative control levels. [See the table below, and also see **administrative control levels** earlier in this Glossary.]

Radiation dose rate: The rate at which an individual receives a dose of radiation, for example, mrem per hour. To calculate the total dose received, multiply the dose rate by the time. For example, 20 mrem per hour times 5 hours equals 100 mrem.

Radioactive: A word which describes an unstable atom when it emits ionizing radiation.

Radioactive contamination: Radioactive material in an unwanted place. Contamination may be in the form of a liquid, solid or gas. Remember that the words "radiation" and "contamination" do not mean the same thing. Contamination is a **material**. Radiation is a form of **energy**.

Radioactive decay: Radioactive decay is the process of radioactive atoms releasing radiation over a period of time. They do this in order to become stable (nonradioactive). Radioactive decay is also known as disintegration.

Radioactive half-life: Radioactive half-life is the time it takes for one half of the radioactive atoms present to decay.

Radioactive material: Any material containing (unstable) radioactive atoms that emit radiation.

Radioactivity: Radioactivity is the process of unstable (or radioactive) atoms trying to become stable. This is done by emitting radiation from the nucleus.

Radiological buffer area (RBA): An area which provides secondary boundaries to minimize the spread of radioactive contamination and to limit doses to general employees who have not been trained as radiological workers.

Radiological posting: A sign, marking or label that indicated the presence of radiation or radioactive materials, and which may indicate radiation levels and entry requirements.

Summary of Radiation Dose Limits and Control Levels

	DOE Radiation Dose Limit	**DOE** Administrative Control Level	**Facility** Administrative Control Level (2)
Whole Body	**5 rem / year**	**2 rem / year**	
Extremities	**50 rem / year**	**30 rem / year**	
Skin and other organs	**50 rem / year**	**30 rem / year**	
Lens of the eye	**15 rem / year**	**9 rem / year**	
Embryo / fetus	**500 mrem / year**	**(1) XXXXX**	
Members of the public & minors	**100mrem/year**	**(1) XXXXX**	

Notes: 1) xxxxxxxx indicates that the DOE Radiation Dose Limit applies.
2) Enter the Facility Administrative Control Levels for your facility.

Radiological work: Any work that requires the handling of radioactive material or which requires access to radiation areas, high radiation areas, contamination areas, high contamination areas or airborne radioactivity areas.

Radiological work permit (RWP): A document used to establish radiological controls for entry into radiologically controlled areas. The RWP informs workers of radiological conditions and entry requirements, and provides a record which relates workers' exposures to specific work activities.

Radiological worker: A worker who has the potential of being exposed to more than 100 mrem (1 millisievert) per year. A person who completes Radiological Worker I or Radiological Worker II training is considered a radiological worker. A radiological worker might also be called a **radiation worker** or **radworker**.

Radiologically controlled area: An area to which access is restricted because of the potential for radiation exposure or radioactive contamination.

Radiosensitivity: A term used to indicate the relative sensitivity of a particular organ to ionizing radiation.

Radon: A naturally occurring radioactive gas present in some soil and rocks. Radon gas can accumulate in unventilated areas such as basements. Radon is an alpha emitter.

Refresher Training: Training for radiological workers which is scheduled on the alternate year when full radiological worker retraining is not required.

Removable contamination: Contamination (radioactive material) that is easily transferred by casual contact, wiping, brushing, touching, washing or by air movement.

Respiratory protective equipment: Respirators used to protect personnel from the inhalation of radioactive materials or hazardous chemical substances.

Roentgen (R): A unit for measuring the intensity of gamma and x-radiation in air.

Roentgen equivalent man (rem): A unit used to measure the dose equivalence of radiation exposure. That is, the biologically effect of the exposure.

Sievert (Sv): A unit used to measure dose equivalent. One sievert equals 100 rems.

Sealed radioactive source: Radioactive material that is sealed into a container or capsule so that the material cannot escape under normal circumstances. A sealed radioactive source may emit radiation.

Self reading pocket dosimeter (SRPD): A direct reading device that provides an estimate of the current accumulated radiation dose. Also called a **pocket ionization chamber (PIC)**, a **direct reading dosimeter (DRD)**, or a quartz fiber (pocket) dosimeter.

Shielding: A method of reducing radiation exposure by placing a physical barrier which absorbs radiation between the source of radiation and the worker. The more penetrating the radiation is, the thicker or denser the shielding needs to be.

Soil contamination area: An area where surface or subsurface contamination levels exceed specified limits.

Somatic effect: Radiation effects that appear in nonreproductive cells of the exposed individual. Somatic effects can result in cancer.

Stay time: The length of time that a worker is allowed to remain in a radiation or high radiation area. Remaining in the area beyond the stay time may result in over exposure to radiation.

Step-off pad: An area between the contaminated and non-contaminated areas that is used to allow exit of personnel or removal of equipment.

Sticky pad: A step-off pad which has a tacky or sticky surface to reduce the potential for inadvertently tracking contamination out of the contaminated area.

Terrestrial radiation: Radiation from radioactive materials in the earth's crust.

Thermoluminescent dosimeter (TLD): A personal monitoring device that contains crystals that are sensitive to ionizing radiation enclosed in a plastic case.

Time: A method of reducing radiation exposure by limiting the time that a worker spends in a radiation area.

Unusual occurrence: A non-emergency occurrence that has significant impact or potential for impact on safety, environment, health, security or operations.

Very high radiation area (VHRA): An area where radiation exposure is greater than 500 rads per hour.

Waterborne contamination: Radioactive material in water.

Whole body counter: A device used in the laboratory to measure the internal dose of radiation from radioactive materials that have accumulated in the body.

Whole body dose: The sum of the radiation dose equivalent from both internal and external radiation exposures.

Abbreviations and Acronyms

ACL	Administrative control level
ALARA	As low as reasonably achievable
ALI	Annual limit of intake
ARM	Area radiation monitor
Bq	Becquerel
CAM	Continuous air monitor
Ci	Curie
cpm	Counts per minute
DAC	Derived air concentration
DNA	Deoxyribonucleic acid
DOE	Department of Energy
DRD	Direct reading dosimeter
dpm	Disintegrations per minute
dps	Disintegrations per second
EPA	Environmental Protection Agency
Gy	Gray
HEPA	High efficiency particulate air filter
HP	Health physics; health physicist
IBT	International Brotherhood of Teamsters
ICRP	International Commission on Radiological Protection
mR	Milliroentgen (one one-thousandth (1/1000) of a Roentgen.)
mrem	Millirem (one one-thousandth (1/1000) of a rem.)
NCR	Nuclear Regulatory Commission
OSHA	Occupational Safety and Health Administration
PADI	Pocket alarm dose indicator
PIC	Pocket ionization chamber

Abbreviations and Acronyms (Continued)

QF	Quality Factor
R	Roentgen
rad	Radiation absorbed dose
RAM	Radiation area monitor
RBA	Radiological buffer area
RCM	DOE Radiological Control Manual
rem	Roentgen equivalent man
RWP	Radiological work permit
SOP	Standard operating procedure
SRPD	Self reading pocket dosimeter
Sv	Sievert
TEDE	Total effective dose equivalent
TLD	Thermoluminescent dosimeter
μCi	Microcurie (One one-millionth (1/1,000,000) of a Curie.)

Appendix

APP

(A) Radiation Dose Terms
(B) Working With Radiation Units

Appendix A

Radiation Dose Terms

[The following is taken from the DOE Radiological Control Manual (DOE/EH0256T), April, 1994, pages G-4 to G-7.]

Dose: The amount of energy deposited in body tissue due to radiation exposure. Various technical terms, such as dose equivalent, effective dose equivalent and collective dose, are used to evaluate the amount of radiation an exposed worker receives. These terms are used to describe the differing interactions of radiation with tissue as well as to assist in the management of personnel exposure to radiation.

Some types of radiation, such as neutron and alpha, deposit their energy more densely in affected tissue than gamma radiation and thereby cause more damage to tissue. The term dose equivalent, measured in units of rem [or Sv], is used to take into account this difference in tissue damage. Therefore 1 rem of gamma radiation causes damage equivalent of 1 rem from alpha radiation. However, it takes one-twentieth as much energy from alpha radiation, as compared with gamma radiation, to produce this 1 rem dose equivalent.

Definitions for dose terms necessary for various exposure calculations and record keeping purposes include the following:

Absorbed dose (D): Energy absorbed by matter from ionizing radiation per unit mass of irradiated material at the place of interest in that material. The absorbed dose is expressed in units of rad (or gray) (1 rad = 0.01 gray).

Collective dose: The sum of the total effective dose equivalent values for all individuals in a specified population. Collective dose is expressed in units of person-rem (or person-sievert).

Committed dose equivalent (HT,50): The dose equivalent calculated to be received by a tissue or organ after a 50-year period after the intake of a radionuclide into the body. It does not include contributions from radiation sources external to the body. Committed dose equivalent is suppressed in units of rem (or sievert).

Committed effective dose equivalent (HE,50): The sum of the committed dose equivalents to various tissues in the body (HT,50), each multiplied by the appropriate weighting factor (WT). That is HE,50 = ΣWTHT,50. Committed effective dose equivalent is expressed in units of rem (or sievert).

Cumulative total effective dose equivalent: The sum of the total effective dose equivalents recorded for an individual for each year of employment at a DOE or DOE contractor site or facility, effective January 1, 1989.

Deep dose equivalent: The dose equivalent derived from external radiation at a tissue depth of 1 cm in tissue.

Dose equivalent (H): The product of the absorbed dose (D) (in rad or gray) in tissue, a quality factor (Q) and all other modifying factors (N). Dose equivalent is expressed in units of rem (or sievert) (1 rem = 0.01 sievert).

Effective dose equivalent (HE): The sum of the products of the dose equivalents received by specified tissues of the body (HT), and the appropriate weighting factors (WT). That is HE = ΣWTHT. It includes the dose from radiation sources internal and/or external to the body. The effective dose equivalent is expressed in units of rem (or sievert).

External dose or exposure: That portion of the dose equivalent received from radiation sources outside the body (e.g., “external sources”).

Internal dose or exposure: That portion of the dose equivalent received from radioactive material taken into the body (e.g., “internal sources”).

Lens of the eye dose equivalent: The external exposure of the lens of the eye taken as the dose equivalent at a tissue depth of 0.3 cm.

Quality factor: The principal modifying factor used to calculate the dose equivalent from the absorbed dose. The absorbed dose (expressed in rad or gray) is multiplied by the appropriate quality factor (Q).

Shallow dose equivalent: The dose equivalent deriving from external radiation at a depth of 0.007 cm in tissue.

Total effective dose equivalent (TEDE): The sum of the effective dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures). Deep dose equivalent to the whole body may be used a effective dose equivalent for external exposures.

Weighting factor (WT): The fraction of the overall health risk, resulting from uniform, whole body irradiation, attributable to a specific tissue (T). The dose equivalent to the affected tissue, HT, is multiplied by the appropriate weighting factor to obtain the effective dose equivalent contribution from that tissue.

Whole body: For the purposes of external exposure, head, trunk (including male gonads), arms above and including the elbow, and legs above and including the knee.

Appendix B

Working With Radiation Units

I. The Units

There are several different units that we use to measure radiation. These include:

A. To measure the energy of gamma or x-rays in air:

Roentgen (R)

B. To measure the energy that is absorbed by a material (such as body tissue) from ionizing radiation that penetrates into that material:

Rad ("Radiation absorbed dose")

Gray

Note that the **rad** and the **gray** are two different units for measuring the same thing (absorbed energy). This is similar to the way in which inches and centimeters are two different units for measuring length.

C. To measure "dose equivalent", that is, the equivalent effect of absorbed radiation on tissue:

Rem ("Roentgen equivalent man")

Sievert (Sv)

Note that the **rem** and the **Sv** are two different units for measuring the same thing (dose equivalent: the biological effect of absorbed radiation). This is similar to the way in which rad and gray are two different units for measuring absorbed radiation)

D. To measure the rate at which the dose equivalent is received:

Rem per hour (rem/hr)

Sievert per hour (Sv/hr)

Note that the **rem/hr** and the **Sv/hr** are two different units for measuring the same thing (the rate at which dose equivalent is received).

E. To measure the strength of a radiation source, including radioactive contamination, in terms of the rate at which it is decaying and giving off radiation:

Disintegrations per minute (dpm)

Disintegrations per second (dps)

Becquerel (Bq)

Curie (Ci)

Note that these are four different units for measuring the same thing (the rate at which a radioactive source decays and gives off radiation).

F. To measure what a radiation survey instrument “sees” which is always less than what is actually happening:

Counts per minute (cpm)

Counts per second (cps)

Note that these are two different units for measuring the same thing (what the instrument “sees”). The reason this is different than measuring how many disintegrations are actually happening, is because the instrument is not perfect. For example, if the instrument has an efficiency of 50%, then it only records one-half of the actual disintegrations.

II. Converting Between Different "Sizes" of the Same Unit

The things that we need to measure (absorbed dose, dose equivalent, radioactive decay, etc.) happen in very different amounts in different situations. For example, a small, weak radiation source might emit just a little bit of radiation, while a large, strong source could emit millions or billions of times more. We need different sizes of units: little units for small quantities, and big units for large quantities.

To get bigger or smaller units, we multiply or divide by ten, or by one hundred, or by one thousand. This is just like the way our money system works. If you want to buy a movie ticket, you might pay seven dollars. To buy a candy bar you might pay fifty cents (before you go to the theater!). For a stereo you could lay out a few "C's". To buy a new car, you would pay several "grand".

Cents, dollars, C's and grand all measure different sizes of the same thing: "cost". They are related to each other by multiplying or dividing by 10, 100, or 1000:

1 dollar = 100 cents	1 cent = 1/100 of a dollar
1 "C" = 100 dollars	1 dollar = 1/100 of a "C"
1 grand = 1000 dollars	1 dollar = 1/1000 of a grand

The number that we use to go from one size unit to another size unit is called a conversion factor. For example, if we have 39 dollars, and we want to know how many cents this is, we multiply by the conversion factor of "100 cents per dollar":

39 dollars times 100 cents per dollar = 3,900 cents

A scientist would write it this way:

$$39\ \cancel{\text{dollars}} \times \frac{100\ \text{cents}}{1\ \cancel{\text{dollar}}} = 3{,}900\ \text{cents}$$

The word "per" means "divided by". "100 cents per dollar" means "100 cents divided by 1 dollar."

Notice how the units cancel. If the same unit is on the "top" and on the "bottom", them you can cancel them, as indicated by the lines through "dollar". If you do a problem like this, and the units cancel so that all that's left is the unit you want, then you probably did the problem correctly!

For radiation dose equivalent, we use units that are related by a conversion factor of 1/1000. The prefix “milli” means 1/1000. We can write “milli” as in millirem, or just write the “m” as in mrem, which means the same thing:

1 millirem = 1/1000 rem	1 rem = 1000 millirem
1 mrem = 1/1000 rem	1 rem = 1000 mrem

Similarly for radiation dose we use:

1 millirad = 1/1000 rad	1 rad = 1000 millirad
1 mrad= 1/1000 rad	1 rad = 1000 mrad

For radioactivity we often use conversion factors of 1/1,000,000 or even 1/1,000,000,000. “Micro” means 1/1,000,000 (one millionth). The abbreviation for micro is “μ“, which is a Greek letter. “Pico” means 1/1,000,000,000 (one billionth). The abbreviation for pico is “p”. The abbreviation for curie is Ci:

1 microcurie = 1/1,000,000 curie	1 curie = 1,000,000 microcurie
1 μCi = 1/1,000,000 Ci	1 curie = 1,000,00 μCi
1 picocurie = 1/1,000,000,000 curie	1 curie = 1,000,000,000 picocurie
1 pCi = 1/1,000,000,000 Ci	1 curie = 1,000,000,000 pCi

Here are some examples of how to work with these conversion factors:

How many mrem are there in 5 rem? $5 \cancel{\text{rem}} \times \frac{1000 \text{ mrem}}{1 \cancel{\text{rem}}} = 5{,}000 \text{ mrem}$

How many mrad are there in 17 rad? $17 \cancel{\text{rad}} \times \frac{1000 \text{ mrad}}{1 \cancel{\text{rad}}} = 17{,}000 \text{ mrad}$

How many μCi are there in 8.5 Ci? $8.5 \cancel{\text{Ci}} \times \frac{1{,}000{,}000\ \mu\text{Ci}}{1 \cancel{\text{Ci}}} = 8{,}500{,}000\ \mu\text{Ci}$

How many mrem are there in 6.8 rem? $6.8 \cancel{\text{rem}} \times \frac{1000 \text{ mrem}}{1 \cancel{\text{rem}}} = 6{,}800 \text{ mrem}$

How many pCi in 1.6 Ci? $1.6 \cancel{\text{Ci}} \times \frac{1{,}000{,}000{,}000 \text{ pCi}}{\cancel{1} \text{ Ci}} = 1{,}600{,}000{,}000 \text{ pCi}$

Now try converting in the other direction. Suppose you had 2387 cents and you want to know how many dollars this is:

$$2387 \text{ cents} \times \frac{1 \text{ dollar}}{100 \text{ cents}} = 23.87 \text{ dollars}$$

Similarly:

How many rem are there in 7000 mrem? $7000 \text{ mrem} \times \frac{1\text{rem}}{1000 \text{ mrem}} = 7 \text{ rem}$

How many Ci in 3,200,000 μCi? $3{,}200{,}000 \ \mu\text{Ci} \times \frac{1\text{Ci}}{1{,}000{,}000 \ \mu\text{Ci}} = 3.2 \text{ Ci}$

How many rad are there in 4400 mrad? $4400 \text{ mrad} \times \frac{1\text{rad}}{1000 \text{ mrad}} = 4.4 \text{ rad}$

When we change the size of the units, we are not changing the size of the thing we measured. For example, the cost of a ticket is the same whether we pay seven dollars or seven hundred cents. A table is the same length even if one time we measure it as five feet long, and another time we measure 60 inches.

If you received a dose equivalent of 0.4 rem, and you convert this to 400 millirem, you still received the same amount of radiation.

By the way: $0.4 \text{ rem} \times \frac{1000 \text{ mrem}}{1 \text{ rem}} = 400 \text{ mrem}$

Why do we go through this if the results mean the same thing? We do this so that we can use units that are in the same size range as the thing we measure. It's easier to say 2 miles than to say 10,560 feet. It's easier to say that a small radiation source has an activity of 60 pCi than to say that it's sixty billionth of a curie.

III. Converting Between Different Units

Unfortunately, there are different systems of units. DOE is in the process of changing over from the "old" system which used rems, rads and curies, to the "new" system which uses sieverts, grays and becquerels.

Fortunately, there are simple relationships between these two sets of units:

1 sievert = 100 rem	1 rem = 1⁄100 of a sievert
1 Sv = 100 rem	1 rem = 0.01 Sv
1 gray = 100 rad	1 rad = 1⁄100 of a gray
1 Gy = 100 rad	1 rad = 0.01 Gy

One Becquerel is equal to one disintegration per second. A Curie is equal to 37 billion disintegrations per second. This means that:

1 Curie = 37,000,000,000 Becquerel   1 Becquerel = 1⁄37,000,000,000 of a Curie

1 Ci = 37,000,000,000 Bq   1 Bq = 0.000000037 Ci

Here are some examples of how to work with these conversion factors:

How many Gy are there in 50 rad? $50\ \cancel{\text{rad}} \times \frac{1\ \text{Gy}}{100\ \cancel{\text{rad}}} = 0.5\ \text{Gy}$

How many rem are there in 1.4 Sv? $1.4\ \cancel{\text{Sv}} \times \frac{100\ \text{rem}}{1\ \cancel{\text{Sv}}} = 140\ \text{rem}$

Sometimes it's necessary to use two conversions factors in the same problem:

How many mrad in 2 Gy? $2\ \cancel{\text{Gy}} \times \frac{100\ \cancel{\text{rad}}}{1\ \cancel{\text{Gy}}} \times \frac{1000\ \text{mrad}}{1\ \cancel{\text{rad}}} = 200{,}000\ \text{mrad}$

- notes -