ES&H DIVISION
RADIATION CONTROL DEPARTMENT

Radiation Worker I Training Study Guide

(supplement to SAF801C)

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Thomas
Jefferson
National
Accelerator
Facility

Jefferson Lab
Thomas Jefferson National Accelerator Facility

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Unit 1: Introduction

Radiation worker level one (RW-I) training is required if you make *routine, unescorted* entries into any radiologically controlled area (RCA). This course will provide the knowledge and skills necessary to ensure the safety of you and your co-workers while working with or near radiation sources.

Upon completion of SAF801C (online), you will need to pass a proctored exam (SAF801T); participate in a hands-on demonstration (practical) of what you have learned (SAF801P); read the current General Access Radiological Work Permit (SAF801kd) then e-sign the form acknowledging your understanding of such. Finally, you will apply for a dosimeter via the Radiation Control Department (RadCon or RCD) homepage (https://www.jlab.org/esh/radcon/dosimetry).

The proctored exam can only be taken in the SSC (Bldg. 28), at the User Liaison Office (Bldg. 12), or in the ES&H Building (52). The practical factors exercise can be taken before or after you pass the proctored exam, but must be scheduled in advance. The RCD can provide you with a paper exam if you request one, but the other two locations offer computer-based exams only.

Once you have completed all portions of this training, you will be qualified as a Radiological Worker Level I. This qualification expires after 24 months; at that time, you may re-take this course to help study but you must pass the written or online examination. If you do not re-qualify within 2 years of the expiration date, you will need to start over as though you had never been qualified before.

Direct questions regarding this training, training alternatives, or other training-related radiological issues to the RCD Training Manager (or radcon_train@jlab.org).

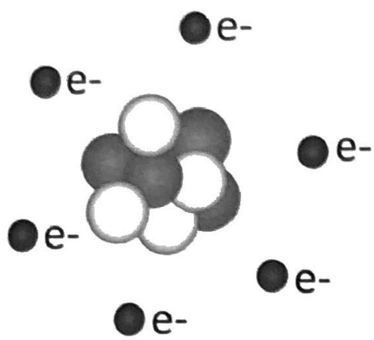
Unit 2: Radiological Fundamentals

By the end of this unit, you should be able to:

- identify the three basic particles in an atom.
- define radioactive material, radioactivity, radioactive half-life, and radioactive contamination.
- define ionization.
- distinguish between ionizing and non-ionizing radiation.
- identify the four basic types of ionizing radiation and their physical characteristics, range, shielding, and biological hazards.
- identify the units used to measure radioactivity and contamination.
- identify the units used to measure dose.
- convert rem to millirem, and millirem to rem.
- calculate total dose, based on dose rate and stay times.

Lesson 1: Atoms & Radiation

All matter is composed of atoms, and all atoms are composed of three major particles. The nucleus of an atom contains the charge-less **neutrons** and positively charged **protons**. Negatively charged **electrons** orbit the nucleus.



Neutrons and protons are massive, while electrons are about 2000 times lighter. The negative electrons balance out the positive charge from the protons, making the atoms, as a whole, electrically neutral.

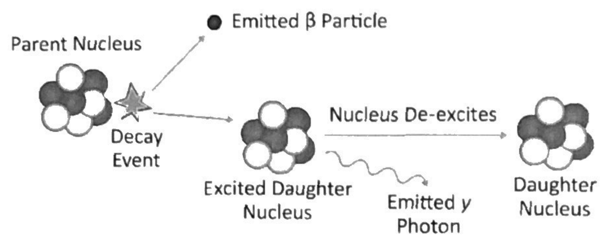
All atoms of a given element have the same number of protons. For example, the nuclei of all carbon atoms have 6 protons, but the number of neutrons in a carbon nucleus can vary. The nucleus of a carbon-12 atom has 6 neutrons while there are 8 in a carbon-14 atom.

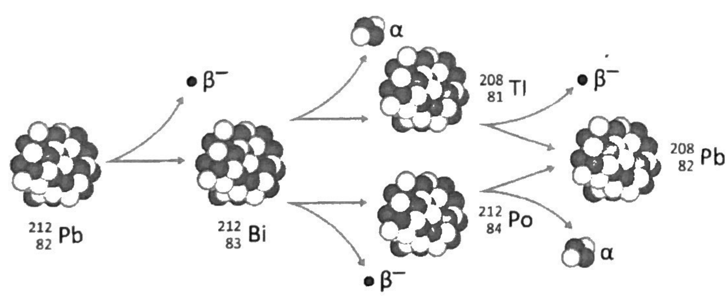
The ratio of neutrons to protons in an atom determines its stability. If an atom has too many or too few neutrons compared to the number of protons, it is unstable. Atoms with unstable nuclei have too much energy in the nucleus, making them radioactive. Material containing unstable atoms is referred to as **radioactive material.**

Radioactive material exists in nature. There is uranium in the earth's crust; a small amount of all potassium is radioactive; and, all carbon-containing matter, including humans, contains a small amount of carbon-14 which is also radioactive.

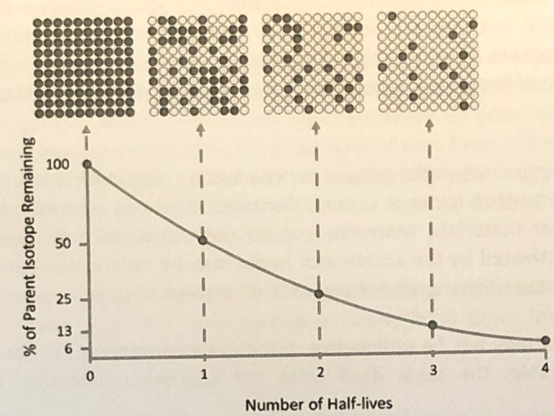
Sometimes, otherwise stable materials are made radioactive – a process known as **activation**. In nuclear reactors activation occurs when neutrons produced by the reactor are captured by materials in and around the reactor. At Jefferson Lab (JLab) we use our accelerators to bombard materials with very high-energy electrons which can also cause materials to become radioactive.

The nuclei of radioactive atoms need to release their excess energy. The energy is released in the form of waves or particles and is referred to as **radiation**. The process of a radioactive atom releasing energy is referred to as **radioactive decay**. Once a radioactive atom has decayed, it is no longer the same kind of atom. For example, carbon-14, which we'll call the parent, becomes nitrogen-14 - the daughter product - when it decays. Daughters may be stable or radioactive. Sometimes there are multiple generations of parents and daughters, referred to as a decay chain. Such chains occur often in nature.

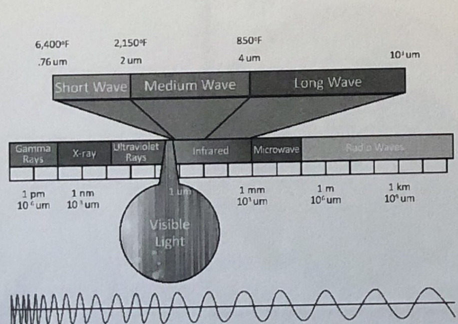




One cannot predict when a given radioactive atom will decay; it's a random process. However, measurements of the decay of a large number of radioactive atoms of a specific type (known as isotopes), allows for accurate determination of that isotope's fundamental **rate of decay**. We refer to this property as an isotope's **half-life**. Half-life is the time it takes for half of the radioactive atoms in any sample of a given isotope to decay. Some isotopes, like carbon-14, have very long half-lives, while others, like oxygen-15, have half-lives that are quite short.

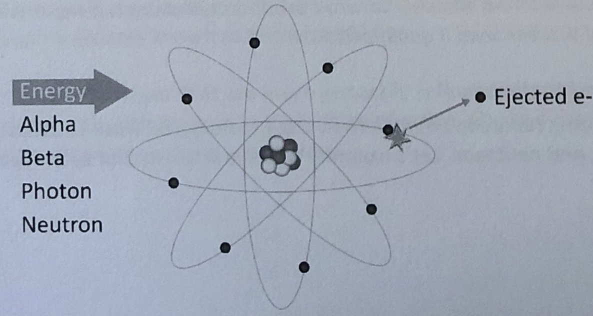


Lesson 2: Radiation vs. Radioactivity



We defined radiation as energy emitted in the form of waves or particles. Radiation is emitted from a source, such as a radioactive atom, and travels through materials in its path. This definition is not very specific though. There are actually many different types of radiation, such as light (visible, UV and infra-red). There are also microwaves, radio waves, and so on. The radiation we will focus on throughout this course is special because it is ionizing.

Ionizing radiation has the ability to strip electrons from an atom with which it interacts once released from its source – known as **ionization**.

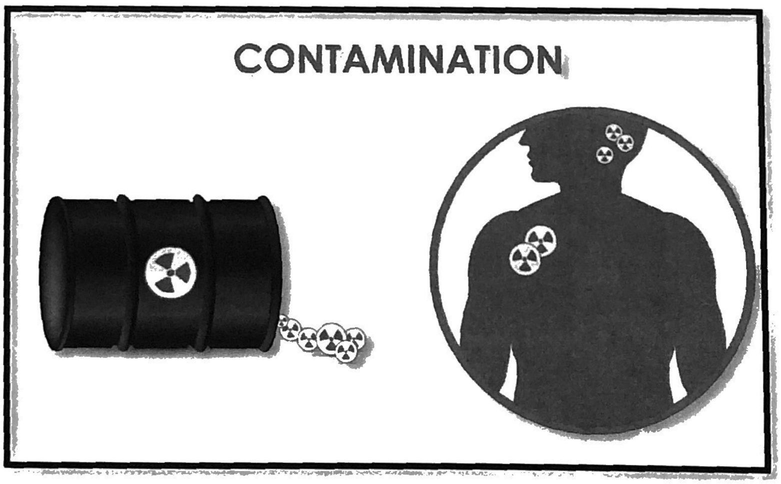


The result is a positively charged atom and the now free electron. Collectively, they are called **an ion pair**. From this point forward we'll be talking about ionizing radiation, but we will use the term radiation, which is common practice.

It is also important that you clearly understand the difference between radiation and radioactivity. People often use the terms interchangeably, but they are not the same. **Radioactivity** is a characteristic of certain materials that emit excess energy in order to become stable. **Radiation** is the energy being emitted. As radiation is emitted over the course of several half-lives, the radioactivity of a material decreases along with the intensity of the emitted radiation.

Another important concept you must understand is contamination. **Contamination** is radioactive material in an unwanted place and in a form that is easily spread. Contamination can be problematic because it can easily transfer to people and other materials. Materials can be radioactive without being contaminated. A metal component that has been activated by the accelerator beam may be radioactive because it emits radiation, but touching its surface will not cause the transfer of any of that material onto you.

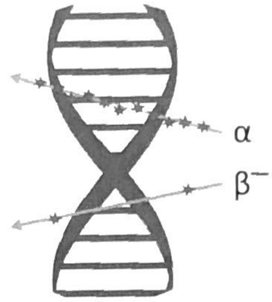
On the other hand, an object may not be radioactive, but can be contaminated. For example, if you spill some radioactive liquid onto a table, the table itself does not become radioactive, but its surface has been contaminated.



Contamination is not a big problem at Jefferson Lab, but working in a contaminated area requires special training. As a qualified RW-I, you will NOT be allowed to work around contaminated materials. *Work in Contamination Areas requires Radiological Worker level II qualification.*

Lesson 3: Types of Ionizing Radiation

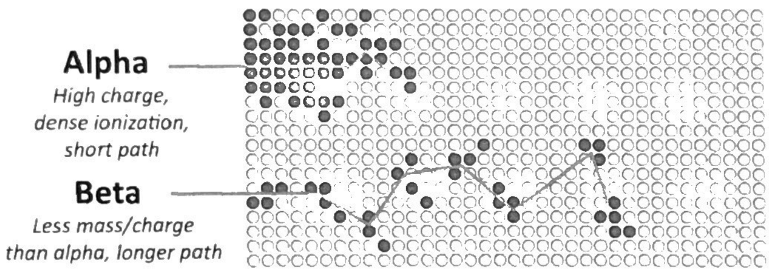
The four basic types of ionizing radiation of concern in most radiological work situations are alpha particles, beta particles, gamma or x-rays, and neutrons. Let's examine the characteristics of each type of radiation.



Alpha particles (α) are emitted during the decay of heavy radioactive atoms such as uranium. Compared to other types of particles, the alpha particle has a relatively large mass. It consists of two protons and two neutrons. It is also a highly charged particle. Because of its mass, the alpha particle moves relatively slowly, and because it travels slowly and is highly charged, it produces a lot of ionizations within a small volume.

With each ionization event, the alpha particle loses some energy. This large energy deposition limits the penetrating ability of the alpha particle to a very short distance. Its range in air is about 1-2 inches. Alpha particles are not considered an external radiation hazard because they are easily stopped by the dead layer of skin. Even a simple piece of paper can shield an alpha particle. However, if alpha-emitting radioactive material is inhaled or ingested, it becomes a source of internal exposure. Internally, the source of the alpha radiation is in close contact with body tissues and large amounts of energy can be deposited within in a small volume.

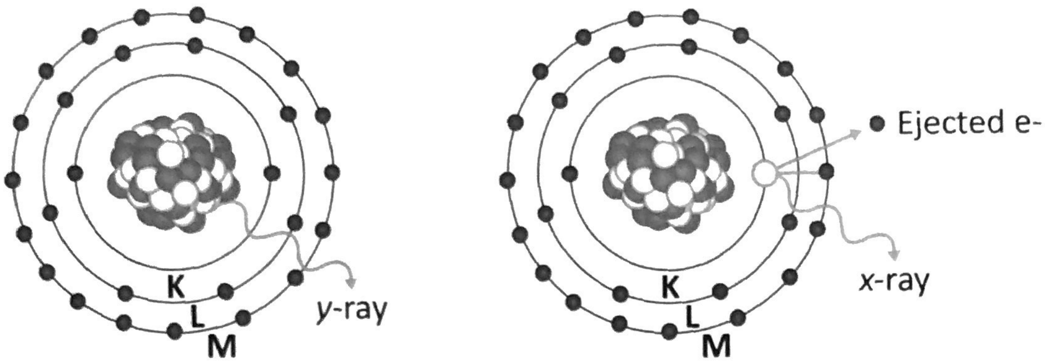
The **beta particle (β)** is an energetic electron or positron emitted during radioactive decay of certain radioactive materials. Compared to an alpha particle, a beta particle is nearly 8000 times less massive and has half the electrical charge.



Beta radiation ionizes through the same mechanisms as an alpha particle. However, because it is not as highly charged, and it moves much faster, the beta particle is not as effective at causing ionizations. It, therefore, travels further before giving up all its energy and finally coming to rest. The beta particle has a limited penetrating ability. Its typical range in air is up to about 10 feet. However, in human tissue, the same beta particle would travel only a few millimeters.

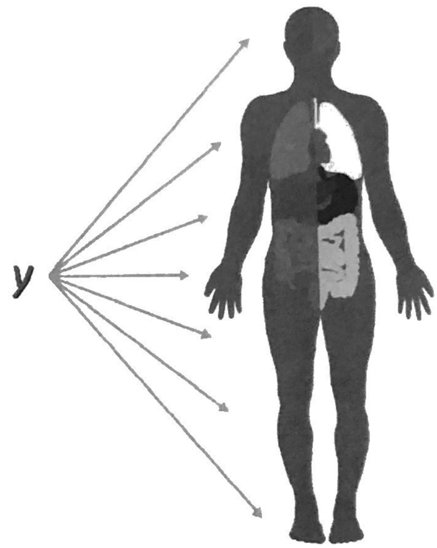
Beta particles are easily shielded by relatively thin layers of plastic, glass, aluminum, or wood. Dense materials such as lead *should be avoided when shielding beta radiation* due to an increase in the production of photons through a process known as **Bremsstrahlung**.

Gamma rays (γ) are electromagnetic waves that are more generally referred to as **photons**. Gamma- rays and x-rays are physically identical; the only difference is in their place of origin. Gamma-rays are emitted by the nuclei of unstable atoms while x-rays originate in the electron cloud.



Photons have no mass or charge, but they can ionize matter as a result of direct interactions with orbital electrons. Because gamma-rays have no charge and no mass, they have a very high penetrating power. Said another way, this type of radiation has a low probability of interacting in matter. In fact, photons have no specifically defined "range" in matter.

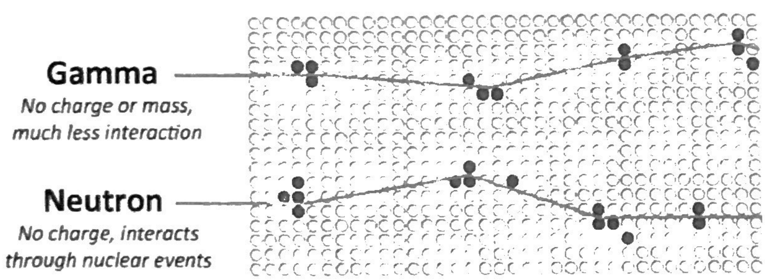
Due to their high penetrating power, gamma-rays and x-rays can result in radiation exposure to the whole body. In fact, photon radiation has the same ability to cause dose to tissue whether the source is inside or outside the body.



Photons are best shielded by very dense materials such as lead, concrete, or steel.

Neutron radiation (n) consists of neutrons that are ejected from the nuclei of atoms. A neutron has no electrical charge. Because neutrons do not experience electrostatic forces, they have a relatively high penetrating ability and are difficult to stop. Like photons, their range is not absolutely defined. The distance they travel depends on the probability for interaction in a particular material.

You can think of neutrons as being "scattered" as they travel through material, with some energy being lost with each scattering event.



Not to scale

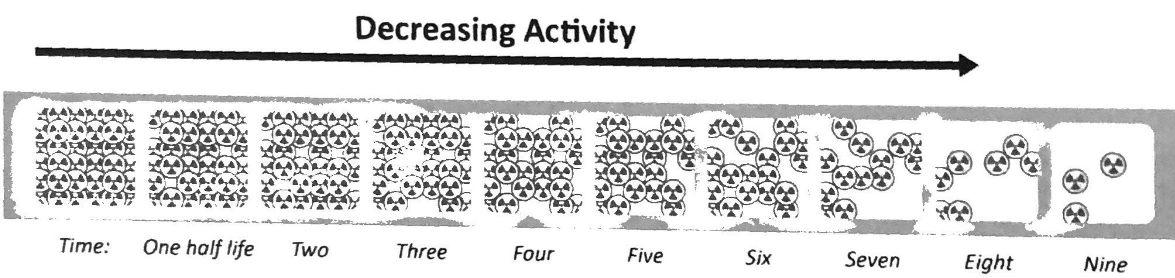
Moderate- to low-energy neutron radiation is best shielded by materials having a high hydrogen content (such as water or concrete). High-energy neutrons, on the other hand, are best shielded by more dense materials such as steel or lead. Sometimes a multi-layered shield will be used to first slow down very "fast" neutrons, and then absorb the "slow" neutrons.

Like photon radiation, neutrons are an external "whole body" hazard due to their high penetrating ability.

We have very few sources of alpha radiation at Jefferson Lab; these consist mostly of calibration sources owned by RadCon. A few neutron sources are also available. In addition, neutrons are produced when the accelerator beam is on, but they are generally not of great concern outside the beam enclosure. While working at the Lab your primary exposure to radiation will come from working around activated materials in the beam enclosure; these materials emit betas and gammas.

Lesson 4: Units of Measurement

Now that you clearly understand the difference between radioactivity and radiation, it is time to quantify them. The amount of radioactive material in a given object can be visualized by thinking of the unstable atoms in the material and the rate at which they decay.



The rate of decay is measured in units of **curies (Ci)**. One curie is the equivalent of 2.2 x 10^{12} atoms decaying per minute! Since the curie is a large number of decays or disintegrations per minute, sub-units of the curie such as the microcurie (μCi – one millionth of a curie) or millicurie (mCi – one thousandth of a curie) are often used.

One disintegration per second is referred to as a **becquerel (Bq)**, another unit for measuring radioactivity. Disintegrations per minute, or dpm, is a unit of activity that is often used when quantifying surface contamination. For example, when using a frisker to measure contamination, the instrument reading in counts per minute is converted to disintegrations per minute using the instrument's counting efficiency.

$$dpm = \frac{cpm}{efficiency}$$

When people are exposed to radiation, the energy of the radiation is absorbed by the body. This does not make the person radioactive or cause them to become contaminated. An analogy would be to shine a bright light upon your body. The body absorbs the light or energy, and in some cases the absorption of the light energy may cause noticeable heating in the body tissues. However, your body does not emit light after it has absorbed it. When exposed to ionizing radiation, your body also absorbs the energy. As this absorption takes place, the tissues of your body may be damaged by the penetration and conversion of the radiation energy.

Since absorption of radiation can damage tissue, a way to measure that damage and to ensure it is kept to a minimum, is necessary. The amount of radiation energy absorbed in an object is known as **dose**. The special unit for measuring dose in a person, called the **equivalent dose**, is the **rem**. The rem is a "special unit" because it does not just quantify the absorbed energy, it also accounts for the differences in the amount of biological harm done by different types of radiation (more on this in a moment). Since the rem is a fairly large unit, radiation dose is usually recorded in thousandths of a rem - or millirem (mrem).

Technically, when doses greater than 10 rem are received in a short time, this unit of measure is no longer applicable. Instead, for doses above 10 rem we use the rad, which will be discussed shortly.

Other related units are used to make radiation measurements. You will hear several terms such as "exposure", "dose", or "absorbed dose" associated with these units. Since these terms are used frequently, and have similar meanings, they are mentioned here for comparison. The units discussed below are among the most common English units used – the limitations of each are described.

The **Roentgen (R)** is a unit for measuring **exposure** and is defined *only for the effects of photons (gamma or x-rays) in air*. The Roentgen is essentially a measure of how many ion pairs are formed in a given volume of air when it is exposed to photons. It is not a measure of energy absorbed, or dose, and does not relate to the biological effect of radiation in the human body.

The **rad** is a unit for measuring **absorbed dose** in any material. Absorbed dose results from energy being deposited by the radiation, and applies to all types of radiation. It does not, however, take into account the amount of biological harm that different types of radiation have on the human body. Therefore, it can be used as a measure of energy absorbed by the body, but not as a measure of the relative biological effect, harm, or risk to the body.

As stated earlier, the rem is the unit for measuring harm to the human body, also known as equivalent dose. The rem takes into account the absorbed dose and the relative biological effectiveness of the type of radiation producing the dose. The rem is a measure of the relative harm or risk caused by a given dose of radiation when compared to any other doses of radiation of any type. Occupational radiation dose is recorded in rem.

The units Roentgen, rad, and rem can sometimes be acceptably interchanged. For instance, for gamma radiation, an exposure to **1 R** causes an absorbed dose in a person of about **1 rad**, which results in an equivalent dose of **1 rem**. This is due to the definitions of the units and the relative biological effectiveness of gamma radiation. An absorbed dose of 1 rad from fast neutrons, however, would result in an equivalent dose of about 10 rem (because the neutrons are more biologically damaging for the same absorbed energy than the gamma radiation).

Dose is the amount of radiation you receive. A dose rate indicates how fast you receive the dose. Dose is usually measured in mrem while dose rates are measured in mrem/hr.

All of the units of measure are recorded in units and subunits. It's important to be able to convert the base units to subunits and conversely, the subunits to base units. As the units of rad and rem are very large, we often want to express them in terms that are smaller than the original unit. This conversion is done by moving the decimal, usually three spaces at a time. We will use the rem as an example:

μ(micro) m(illi)←rem (base)→k(ilo) M(ega) G(iga)

- when converting from rem to millirem (mrem), move the decimal to the right

  1 rem = 1000 mrem

- when converting from mrem to rem, move it to the left

  5 mrem = **0.005 rem**

Review Questions: Unit 2

1. Ionizing radiation may be defined as__________, in the form of __________ or __________, which has the ability to __________ matter.
   a. energy, waves, particle, ionize
   b. energy, waves, particle, activate
   c. particles, energy, momentum, ionize
   d. radioactivity, waves, particles, ionize

2. Unstable atoms which give off radiation when they decay are known as __________ material.
   a. radiating
   b. radioactive
   c. ionizing
   d. activated

3. Radioactive material on surfaces or in liquids, which might be easily transferred to surfaces or personnel, is known as __________.
   a. radioactivity
   b. radiation
   c. activation
   d. contamination

4. Ionization is the process of removing __________ from __________.
   a. atoms, materials
   b. electrons, atoms
   c. bonds, DNA
   d. radiation, atoms

5. After two half-lives, what percent of the original radioactive material will remain?
   a. 50%
   b. 25%
   c. 20%
   d. 10%

6. If you stand in an area where the dose rate is 40 mrem/hr for half an hour, what would your dose be?
   a. 40 mrem
   b. 80 mrem
   c. 20 mrem
   d. 20 rem

7. Exposure to radiation results in a person becoming contaminated.
   a. True
   b. False

8. You are working in a room where the general area dose rate is 3 mrem/hr. If you work in this area for an 8-hour shift, what is your total dose in mrem?
   a. 24 mrem
   b. 3 mrem
   c. 8 mrem
   d. 12 rem

9. The unit ___ takes into account the biological harm from different types of radiation.
   a. R
   b. rad
   c. rem
   d. Ci

10. A dose of 0.1 rem is equivalent to what dose in mrem.
   a. 0.01
   b. 100
   c. 1000
   d. 1

11. A sample of radioactive material is said to have 22,000 dpm. This means that:
   a. there are 22,000 atoms in the material
   b. every minute, 22,000 atoms escape from the material
   c. every minute, 22,000 atoms decay and give off radiation
   d. the dose rate on the surface is 22,000 mrem/hr

12. The four basic types of ionizing radiation are:
   a. alphas, positrons, negatrons, neutrons.
   b. electrons, protons, neutrons, x-rays.
   c. alphas, betas, gammas, protons.
   d. alphas, betas, gammas, neutrons.

13. Rank the following types of radiation in order of <u>decreasing</u> penetrating power (i.e. #1 is the most penetrating): beta _____ gamma _____ alpha _____
   a. 1, 2, 3
   b. 3, 2, 1
   c. 2, 1, 3
   d. 2, 3, 1

14. Select the radiation forms that are ionizing.
   a. Ultraviolet radiation
   b. RF (microwave) radiation
   c. Alpha particles
   d. Neutron radiation
   e. Laser radiation

15. A good shield for beta radiation would be:
   a. plastic
   b. lead
   c. water
   d. concrete

16. Gamma-rays have no __________or charge, and are, therefore, __________ likely to interact in a given thickness of material than beta particles.
   a. energy, more
   b. energy, less
   c. mass, more
   d. mass, less

Unit 2 Answers

1. a
2. b
3. d
4. b
5. b
6. c
7. b
8. a
9. c
10. b
11. c
12. d
13. c
14. c, d
15. a
16. d

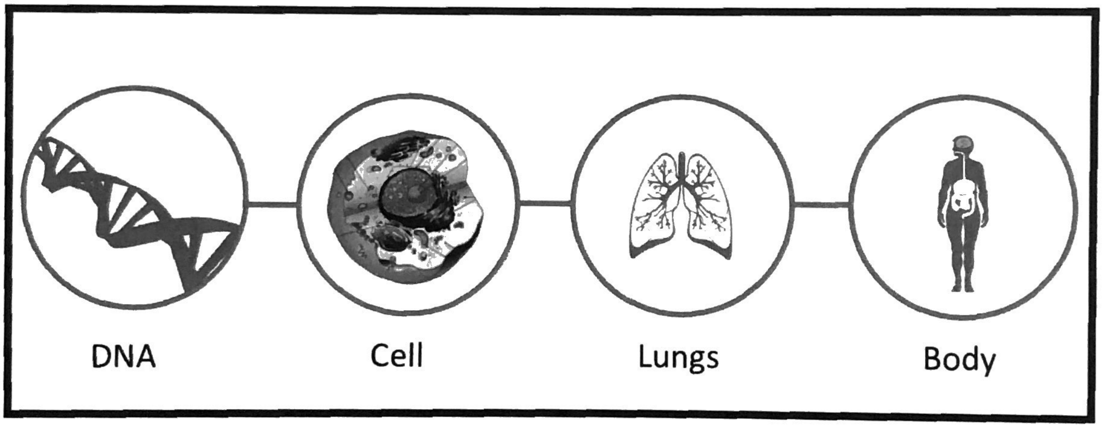
Unit 3: Biological Effects & Sources of Radiation

Upon completion of this unit, you will be able to:

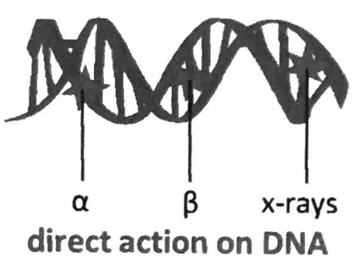
- state the methods by which radiation causes damage to cells.
- identify the possible effects of radiation on cells.
- sort cell types by overall cell sensitivity.
- define the terms chronic dose and acute dose.
- differentiate between chronic and acute dose effects.
- state the LD50/30 dose and definition.
- define the terms somatic effect and genetic effect.
- state the potential effects associated with prenatal radiation exposure.
- compare the biological risks from chronic radiation dose to health risks workers are subjected to in industry and daily life.
- identify the major sources of natural background and man-made radiation.
- identify the average annual dose to the general population from natural background and man- made sources of radiation.

Lesson 1: 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.



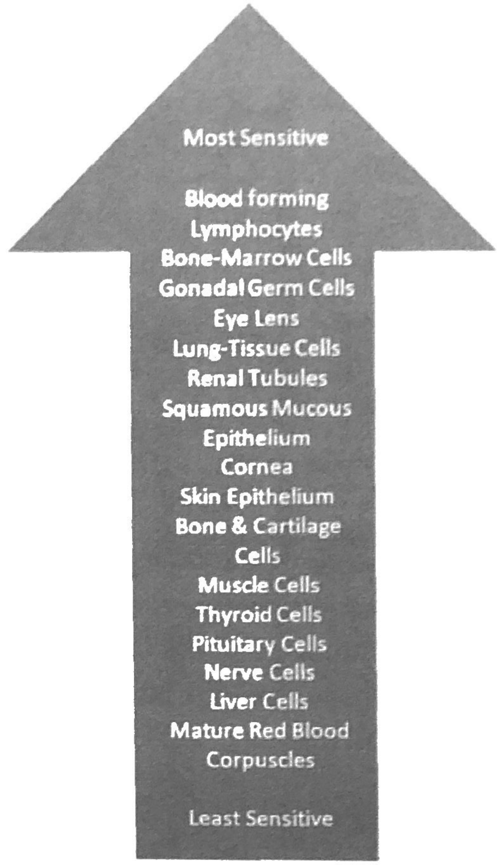
The mechanism by which radiation causes damage to human tissues is through the ionization of atoms, just like in any other material. When an electron that was shared by two atoms to form a molecular bond is dislodged by ionizing radiation, the bond is broken and the molecule falls apart.



When ionizing radiation interacts with cells, it may or may not strike a critical part of the cell. We consider the chromosomes or DNA to be the most critical part of the cell. However, humans are made mostly of water, so chances are much greater that radiation will interact with a water molecule rather than a strand of DNA.

When water molecules are ionized, they may be broken up into various types of other molecules which in turn can interact with more molecules, including DNA. This indirect form of radiation damage is much more common than radiation directly acting on a critical target, but it is no more or less harmful than direct action.

Not all damage to cells is necessarily bad. Although ionizations may form chemically reactive substances, which in some cases alter the structure of cells, these alterations may be the same as changes that occur naturally in the cell and may have no negative effect. In other cases, ionizing events produce limited damage that cells can repair. Thousands of chromosomal aberrations occur constantly in our bodies, but we have effective mechanisms to repair these changes.



In some cases, cell damage results in a harmful outcome. If a damaged cell needs to perform a function before it has had time to repair itself, it will either be unable to perform the function or perform the function incorrectly or incompletely. These altered cells may be unable to reproduce themselves or may reproduce at an uncontrolled rate. Such cells can be the underlying cause of cancer.

Finally, if a cell is extensively damaged by radiation, or damaged in such a way that reproduction is affected, the cell may die. However, cells die all the time; this is only a problem if a large number of cells die in a relatively short period of time.

You should know that all cells are not equally sensitive to radiation damage. In general, cells which divide rapidly and/or are relatively non-specialized tend to be more sensitive to radiation damage than those that are less rapidly dividing and are more specialized.

Lesson 2: Chronic vs. Acute Dose

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

A **chronic dose** is a relatively small amount of radiation received over a long period of time. The body is better equipped to tolerate 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 also has time to replace dead or non-functioning cells with new, healthy ones. This is the type of dose received as a result of occupational exposure.

An **acute dose** is defined as a large dose of *10 rad or more to the whole body* delivered during a short period of time (on the order of a few days at the most). If large enough, an acute dose may result in effects that are observable within a period of hours to weeks.

Acute doses can cause a pattern of clearly identifiable symptoms. These conditions are referred to in general as **Acute Radiation Syndrome (ARS)**. *Radiation sickness symptoms are apparent following acute doses above 200 rad to the whole body.*

As in most illnesses, the specific symptoms, the therapy that a doctor might prescribe, and the prospects for recovery vary from one person to another and are generally dependent on the age and health of the individual. However, it has been well established that acute whole-body doses of 400 to 500 rad result in a statistical expectation that 50% of the population exposed will die within 30 days without medical attention. This is referred to as the **LD50/30 dose**.

The symptoms of ARS are only experienced when the entire body is exposed to large doses of radiation. When the dose is more localized, the effects are different. For example, though 200 rad to the entire body may affect the production of white blood cells causing the onset of ARS, 200 rad to a small patch of skin can result in reddening of the skin similar to a sunburn.

200 to 300 rad to the skin can result in reddening of the skin (erythema), similar to a mild sunburn and may result in hair loss due to damage to hair follicles.

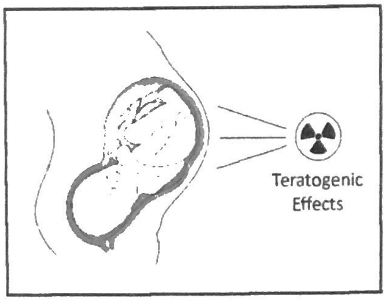
300 rad to the ovaries can result in prolonged or permanent suppression of menstruation.

30 rad to the testicles can result in temporary sterilization.

200 rad to the eyes can cause cataracts.

Lesson 3: Prenatal Exposure vs. Hereditary Effects

Most of the time, when we think of radiation exposure, we talk about risks to the exposed person – these are commonly referred to as **somatic effects**. Somatic effects can be prompt or latent. **Prompt** somatic effects are those that occur soon after an acute dose, while **latent** effects manifest themselves after a time delay of up to several years. Among the delayed effects thus far observed have been an increased potential for the development of cancer and cataracts.

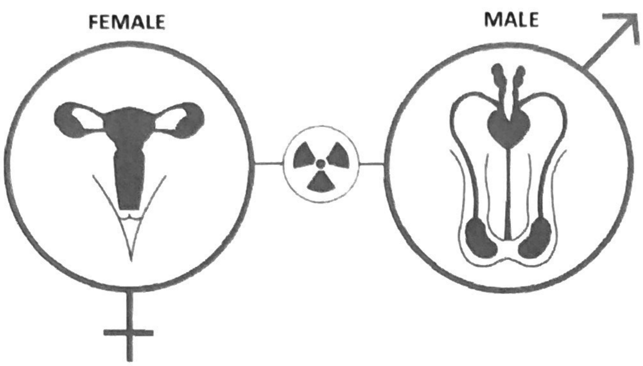


When discussing risks from radiation exposure, we should also think about risks to the embryo or fetus of an exposed pregnant woman and genetic effects. **Teratogenic effects** (or birth defects) can result from the mother receiving an external dose or having an intake of radioactive material while she is pregnant. The embryo and fetus are especially sensitive to radiation damage because the cells are rapidly dividing, but the type of damage which occurs depends on the age of the embryo or fetus at the time of exposure and the magnitude of the dose. Potential effects from *acute* doses of radiation include:

- death of the embryo and birth defects
- growth retardation
- small head and brain size
- mental retardation, and
- childhood cancer

Such effects have been *observed in individuals who received doses above at least 10 rad.* At occupational dose limits, however, the actual probability of any of these effects occurring from exposure of the mother is very small.

Genetic effect ≠ teratogenic effect
Genetic effect = heritable effect

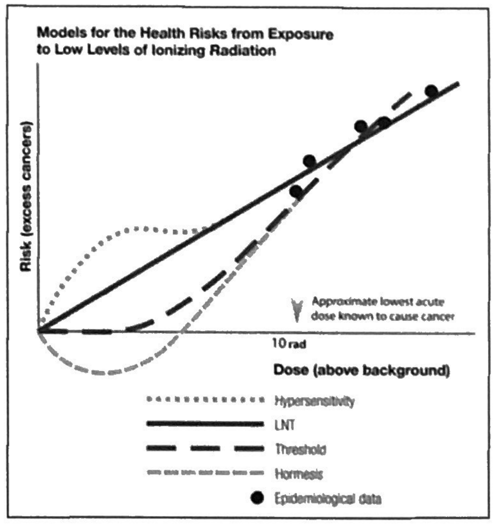


Do not confuse teratogenic effects with **genetic effects**. Genetic, or heritable, effects are abnormalities that may occur in the offspring of individuals whose gonads were exposed to radiation. Genetic effects due to radiation exposure have been studied extensively in plants and animals, but genetic effects have never been observed in humans. The limits used to protect the exposed person from harm are equally effective in protecting future generations.

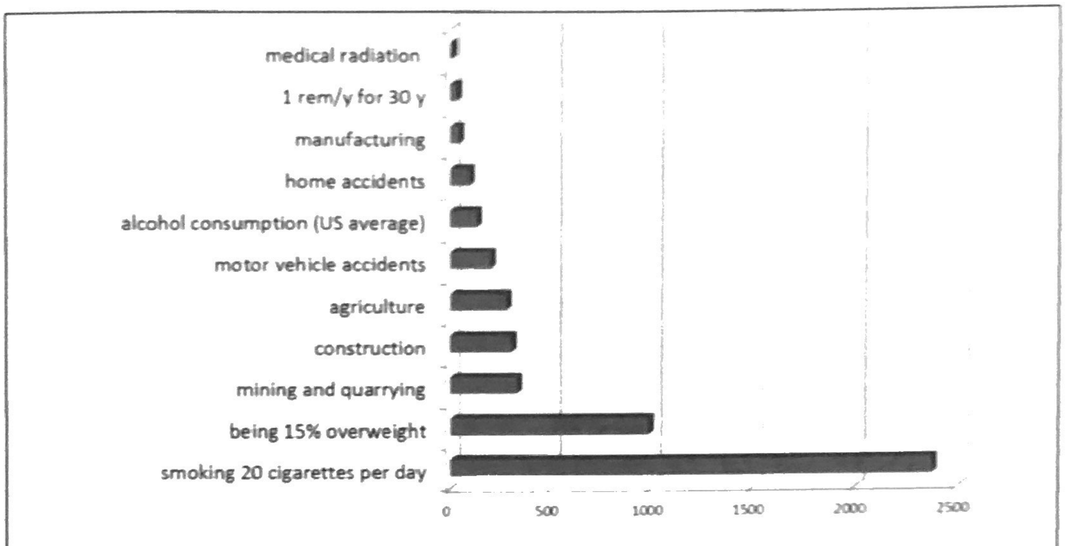
Lesson 4: Evaluating & Comparing Radiation Risks

We have looked at the effects of high- and low-level radiation exposure to both the individual and their offspring. Now, let's put those risks into perspective. Did you know, for example, that the overall risk of developing cancer in your lifetime is 25%? And, if you receive a chronic dose of 400 mrem/y for 30 years, your calculated cancer risk increases by only half a percent.

A discussion of risks cannot occur without some understanding of our risk models. Most of what is known today about the health effects of radiation exposure to humans comes from studies of acute exposures experienced by individuals who survived the World War II bombings of Hiroshima and Nagasaki. Many other groups have been tracked; and, there are numerous scientific studies conducted using mice, insects, and even plants. The high-dose risk data have been extrapolated to try and correlate risks to lower/occupational dose levels. The **linear-no-threshold (LNT) model** of risk vs. dose is based on a conservative extrapolation and is the one most often used to quantify risk. However, you should know that these discussions are statistical in nature and should not be used to predict individual risk, especially not at extremely low levels like 10 mrem.



Acceptance of risk is a highly personal matter, requiring 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 the scientific groups who have studied them. This chart may help you put the potential risk of radiation exposure into perspective by comparing it to other occupations and daily activities.



Adapted from Regulatory Guide 8.29 and Cohen and Lee, "A Catalogue of Risks", Radiation Protection, Vol. 36, June 1979

Note that the radiation-related loss of life expectancy in the chart is based on the assumption that cancer is the cause of death.

Common activities we participate in, some every day, help put risk in perspective; each is calculated to have a one-in-a-million chance of causing death.

ONE in a MILLION CHANCE of CAUSING DEATH

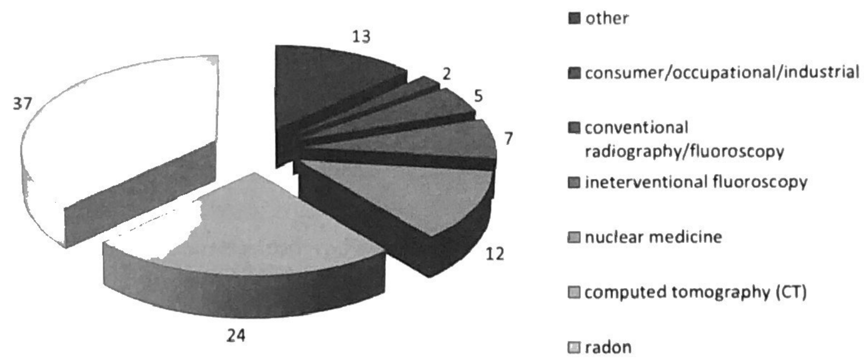
Smoking 1.4 cigarettes (lung cancer)
Radiation dose of 10 mrem (cancer)
Eating 40 tablespoons of peanut butter (liver cancer)
Eating 100 charcoal-broiled steaks (cancer)
Spending 2 days in New York City (air pollution)
Driving 40 miles in a car (accident)
Flying 2,500 miles in a jet (accident)
Canoeing for 6 minutes (accident)

You are not being asked to take the risks of radiation exposure lightly. We assume that any radiation exposure, no matter how small, carries with it some risk. However, we know that, on average, these risks are comparable to or smaller than risks we encounter in other activities or occupations that we consider safe. Since we have extensive control over how much radiation exposure we receive on the job, we can control and minimize these risks. The best approach is to keep our dose As Low As Reasonably Achievable, or ALARA - a term we will discuss in detail in another unit. Remember, minimizing the dose minimizes the risk.

Lesson 5: Background Radiation Sources

We just finished comparing risks from radiation exposure to other risks and you were probably wondering about how much radiation you will be exposed to while working at Jefferson Lab, but do you know that you are exposed to radiation every day?

We live in a radioactive world – there are many natural sources of radiation that have been present since the earth was formed. In addition, over the last century, we have added somewhat to this natural background radiation with man-made sources. The average background radiation, the kind we are all exposed to, is both natural and man-made. Your dose may be somewhat higher if you live in Denver, the mile-high city, instead of at sea level, or if you have a lot of medical diagnostic and treatment regimens that use radiation and radioactivity. On average, however, if you live in the United States, *you will receive 620 mrem per year of **background radiation** from both natural and man-made sources.*



In the pie chart above, radon gas, a natural source of radiation, is the biggest contributor to background dose. This gas is produced by the decay of natural uranium in the soil. Radon, which emits alpha radiation, rises from the soil under houses and can build up in homes, particularly well-insulated homes. In the United States, the average effective whole-body dose from radon is about 200 mrem per year.

Review Questions: Unit 3

1. What happens when a cell is damaged by radiation?
   a. The cell always dies.
   b. The cell may repair the damage and operate normally.
   c. The cell induces radiation poisoning.
   d. There is a high probability of cancer developing.

2. If radiation causes damage to a cell, and the cell is not effectively repaired:
   a. the outcome is always cancer.
   b. any future offspring of the person will carry the mutation.
   c. the cell will not be able to reproduce.
   d. the cell may die.

3. __________ is the mechanism that causes damage to cells from radiation exposure.
   a. activation
   b. ionization
   c. mutation
   d. oxidation

4. The most radiosensitive cells in the body are those that divide ______, and are relatively ______.
   a. rapidly, unspecialized
   b. slowly, specialized
   c. slowly, unspecialized
   d. rapidly, specialized

5. A large dose of radiation in a short period of time is called a(n) __________ dose.
   a. overdose
   b. cumulative
   c. acute
   d. chronic
   e. lethal

6. If a person receives an acute whole-body dose of approximately 10 rad, what <u>prompt visible</u> effects are expected?
   a. Hair loss
   b. Hemorrhaging
   c. Skin-reddening
   d. None

7. A relatively small dose over a long period (e.g., 2 rem/y for 25 years), is known as a(n) _______ dose
   a. overdose
   b. cumulative
   c. acute
   d. chronic
   e. lethal

8. Prenatal exposure refers to radiation dose received:
   a. during childhood
   b. by an embryo/fetus during pregnancy
   c. by the mother during pregnancy
   d. by an adult female prior to her becoming pregnant

9. What effect would be expected for a person who received a dose of 1 rem/y for 50 years?
   a. Cancer
   b. Genetic effect
   c. Early death
   d. None

10. A radiation dose of 1 rem/y for 30 years has a higher risk of cancer than smoking (20 cigarettes per day).
   a. True
   b. False

11. What kind of effect is a burn to the skin as a result of radiation exposure?
   a. prompt somatic
   b. delayed somatic
   c. prenatal
   d. genetic

12. Induction of cancer due to radiation exposure is an example of a ____________ effect.
   a. prompt somatic
   b. latent somatic
   c. prenatal
   d. genetic

13. The risks of genetic effects occurring from radiation are estimated to be _________ than the risks for cancer induction.
   a. greater
   b. less
   c. the same as

14. The risk to a developing embryo/fetus from radiation exposure is greater than for an adult because its cells are __________ and rapidly dividing.
   a. unspecialized
   b. small
   c. childlike
   d. highly specialized

15. How much dose does the average American receive in a year from all sources of background radiation?
   a. 100
   b. 430
   c. 620
   d. 800

16. What is the largest component of the average radiation dose from background sources?
   a. diagnostic x-rays
   b. naturally occurring sources of radiation and radioactivity in the environment
   c. nuclear weapons fallout
   d. industrial radiography
   e. electron beam accelerators

Unit 3 Answers

1. b
2. d
3. b
4. a
5. c
6. d
7. d
8. b
9. d
10. b
11. a
12. b
13. b
14. a
15. c
16. b

Unit 4: Dose Limits & TJNAF Policy

Upon completion of this unit, you will be able to:

- identify the DOE radiation dose limits and TJNAF administrative control levels.
- state the purpose of the administrative control levels at Jefferson Lab.
- state the JSA policy concerning prenatal radiation exposure.
- identify employee responsibilities concerning radiation dose limits and administrative control levels.

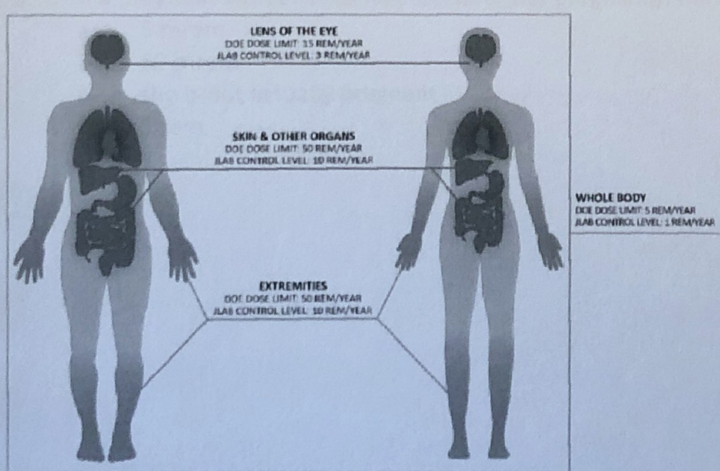
Lesson 1: DOE Radiation Dose Limits & TJNAF Administrative Control Levels

Radiation dose limits and administrative control levels have been established to keep occupational radiation exposures within acceptable bounds. The Department of Energy radiation dose limits are federal law, based upon guidance from national and international experts, scientific groups, and government agencies such as the:

- International Commission on Radiological Protection (ICRP),
- National Council on Radiation Protection and Measurements (NCRP), and
- U.S. Environmental Protection Agency (EPA).

Title 10 of the Code of Federal Regulations describes the protection standards and dose limits that apply to all DOE workers. *The DOE* ***dose limit*** *to the whole body from occupational radiation sources is 5 rem* or 5000 mrem per year. This is the dose you may receive in addition to your background dose. TJNAF, however, has its own more conservative **administrative control level** for Radiological Workers. *The Lab's limit is 1 rem per year*. This lower whole-body dose limit helps ensure that DOE limits are not exceeded and it supports the ALARA concept (discussed in the next unit).

ANNUAL WHOLE BODY DOSE LIMIT BASED ON BOTH INTERNAL & EXTERNAL EXPOSURES



Whole body is defined as extending from the top of the head down to just below the elbows and just below the knees. The whole body includes the locations of most blood-producing and vital organs; the whole-body dose limit is based on the sum of internal and external exposures. Additional limits are applied to the extremities and the lens of the eye, as well as the skin and other organs. For all these limits, the TJNAF administrative control level is 5 times lower than the DOE limit.

The DOE dose limit for members of the public (as well as occupationally exposed minors and all other workers who are not trained as radiation workers) is 100 mrem per year. The Jefferson Lab administrative dose control level for this group is 50 mrem/y.

When members of the public wish to tour a radiologically controlled area (RCA) at Jefferson Lab, they must receive a visitor briefing from RadCon. They will be provided with temporary dosimetry to monitor their dose and must be accompanied by a Radiological Worker I-trained escort at all times. *At no time can a visitor be taken into a radiation area.*

Lesson 2: Prenatal Radiation Exposure Policy

Department of Energy policy states that a female radiological worker should be encouraged to voluntarily notify her employer, in writing, when she is pregnant.

For a **declared pregnant worker**, the dose limit to the fetus is 500 mrem during the entire gestation period. In addition, efforts should be made to avoid exceeding 50 mrem/month. The "declared" pregnant worker and her employer are encouraged to arrange for a mutually agreeable reassignment of work tasks, with no loss of pay or promotional opportunity, such that occupational radiation exposure is unlikely.

At JLab it is unlikely that any radiological worker will be exposed to more than 500 mrem per year, but if you are pregnant and working in radiological areas, you are encouraged to notify RadCon of your pregnancy so your dose is properly monitored. A declaration of pregnancy is a voluntary measure taken by expectant mothers; no special dose limitations are applied without written consent. Contact RadCon with questions regarding this policy.

Lesson 3: Employee Responsibilities

It is every worker's responsibility to comply with the Department of Energy's dose limits <u>and</u> TJNAFs administrative control levels.

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

Review Questions: Unit 4

1. What is the DOE dose limit for the WHOLE BODY?
   a. 1 rem/y
   b. 5 rem/y
   c. 1 mrem/y
   d. 5 mrem/y

2. The extremity dose limit is ________ the whole-body dose limit.
   a. greater than
   b. less than
   c. the same as

3. What is the DOE dose limit for a fetus/embryo for the duration of the pregnancy?
   a. 5 mrem
   b. 50 mrem
   c. 500 mrem
   d. 5 rem

4. How does a worker become classified as "declared pregnant"? She
   a. calls Occupational Medicine
   b. notifies their employer in writing of their pregnancy
   c. is identified as pregnant by her supervision
   d. is prevented from receiving radiation exposure

5. If a pregnant worker does not "declare" her pregnancy, her DOE dose limit is:
   a. 5 mrem
   b. 50 mrem
   c. she is not actually pregnant
   d. 5 rem

Unit 4 Answers

1. b
2. a
3. c
4. b
5. d

Unit 5: Radiation Exposure Minimization

Upon completion of this unit, you should be able to:

- explain the meaning of the ALARA concept as well as recognize the DOE and TJNAF policies for the ALARA program.
- identify ways to reduce external radiation dose.
- list ways a radiological worker can minimize radioactive waste.

Lesson 1: The ALARA Concept

The DOE requires that radiation doses be kept **as low as reasonably achievable** or **ALARA**. The ALARA concept is an integral part of all activities that involve the use of radiation or radioactive materials. This includes the design, construction, and operation of existing and future facilities at Jefferson Lab. The ALARA concept includes reducing both internal and external exposure to ionizing radiation.

As
Low
As
Reasonably
Achievable

The ALARA concept itself grows out of our assumption that any radiation exposure carries with it some risk. This linear-no-threshold (LNT) model of risk vs. dose was discussed in Unit 4, Lesson 4.

Since work that entails radiation exposure is a part of some beneficial endeavor, the ALARA effort is an attempt to balance the assumed risks of radiation exposure against the benefit of performing the work. Department of Energy and TJNAF Management policies regarding the ALARA program are that:

> *There should not be any occupational exposure of workers to ionizing radiation without the expectation of an overall benefit from the activity causing the exposure.* ALARA ultimately means preventing both unnecessary exposure and overexposure.

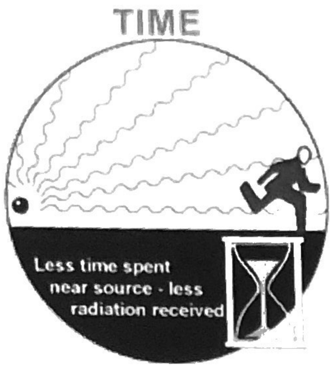
Lesson 2: External Dose Reduction Practices

The three basic protective measures used to reduce *external* exposure are:

- ✓ minimize the time spent in a field of radiation
- ✓ maximize the distance from a source of radiation
- ✓ use shielding whenever possible

Let's look at each of these concepts in more detail.

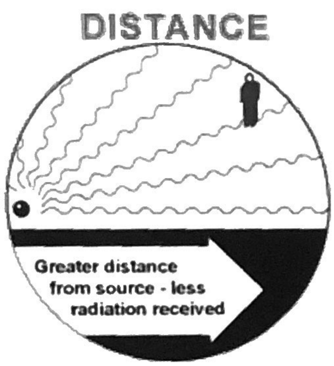
The less time you spend around a source of radiation, the lower your dose. You can minimize the time spent around radiation sources by pre-planning and discussing a task thoroughly prior to entering an area, & using only the number of workers actually required to do the job.



Reduce time around sources by:

- Having all tools ready before entering an area
- Using mock ups and practice runs
- Taking the most direct route to the job site
- Not loitering around radioactive material
- Working efficiently but swiftly
- Doing the job right the first time
- Performing as much work outside the area as possible

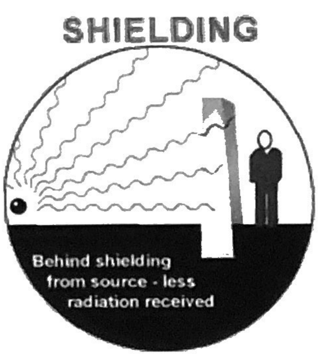
Radiation intensity decreases as you move away from a source. For a small point-like source, the intensity drops by a factor related to the square of the distance, so that a small change in distance from the source can have a large impact on the dose rate. If you double your distance, your dose rate is reduced to one fourth of the original intensity! Clearly, maximizing your distance from a source is an easy way to keep your exposure ALARA. You can always take a step back during a work delay.



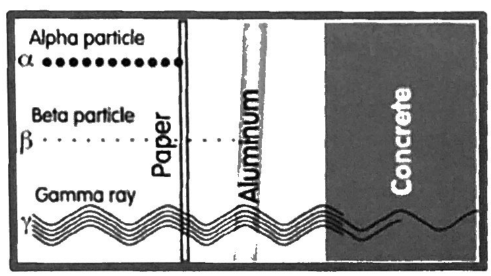
Keep your distance by:

- Being familiar with radiological conditions in the area
- Moving to lower dose rate areas
- Using remote handling devices when possible

Shielding can reduce or prevent radiation exposures, but keep in mind that different materials must be used for different types of radiation. Lead and other dense materials make good shields for gamma radiation, but may not be appropriate for every case due to weight and other physical properties. Take advantage of installed equipment and structures as shielding whenever possible.



NO lead for β



Recall that beta particles are easily shielded with plastic and other lower density materials like aluminum and wood. Lead should not be used to shield beta particles because the interaction of the beta particles with high-density materials leads to the creation of photons referred to as Bremsstrahlung which then require additional shielding. Plastic safety goggles and rubber gloves are sometimes used to shield the eyes and skin of the hands from beta radiation.

Source reduction is another method used for minimizing radiation doses. Source reduction normally involves procedures such as flushing radioactive systems and decontamination to reduce the amount of radioactive material present in or on a system that contributes to radiation levels in an area. Additionally, activation in Lab beam enclosures may be reduced through careful selection of materials used in and around activation sources and by practicing good housekeeping to prevent inadvertent activation or contamination of materials.

When deciding what ALARA measures are worth implementing, we can consider both the cost and time spent reducing the exposure and the extent to which the dose is actually lowered.

Ultimately, implementation of the ALARA concept is the responsibility of all employees and the success of the ALARA program depends on each radiological worker's attitude and actions. Practicing ALARA should be a routine element of your work in radiological areas. You are responsible for:

- knowing and minimizing your exposure.
- complying with all radiological rules and instructions from RadCon personnel.
- being familiar with emergency procedures.
- being alert for and responding to unusual radiological situations.
- knowing where and how to contact RadCon.

Lesson 3: Minimizing Radioactive Waste

The ALARA concept also applies to minimizing radioactive waste. This will reduce personnel dose associated with the handling, packaging, storing, and disposing of radioactive waste. It also reduces costs for TJNAF and can ultimately save valuable space in national waste disposal sites. *Each worker is responsible for minimizing the amount of radioactive waste generated.*

Waste minimization practices include:

- Bringing only the tools, equipment, and supplies you need into a radiological (especially contaminated) areas.
- Unpacking equipment and tools in a clean area to avoid packaging material being added to radiological waste. This includes bulk supplies, like an entire container of bags or gloves. Only bring in what you need.
- Preparing or staging the work area to make cleanup of potential spills easy.
- Disposing of waste materials in the proper containers.
- Having wastes removed from the work area in a timely manner.

Review Questions: Unit 5

1. Since all exposure to radiation is thought to cause some negative biological effects, the ALARA principle is designed to ________ the risk from exposure by keeping exposures as low as reasonably achievable.
   a. increase
   b. eliminate
   c. minimize
   d. guaranty

2. What does ALARA stand for?
   a. As low as radiation allows
   b. As low as reasonably achievable
   c. Alarm levels around Radiation Areas
   d. As limiting as realistically allowable

3. What factors are considered when deciding whether a dose of radiation is "reasonably low"? (select all that apply)
   a. Cost of reducing exposure
   b. Time spent implementing dose-reduction measures
   c. Fear of individual workers
   d. Dose already accumulated

4. Who is responsible for keeping your dose ALARA?
   a. The Radiation Control Department
   b. your immediate supervisor
   c. you, the individual worker
   d. JLab management

5. What are the basic controlling principles in implementing ALARA?
   a. reduce, reuse, and recycle
   b. dosimetry, shielding, and RWPs
   c. time, distance, and shielding
   d. reason, reduction, and shielding

6. You can help minimize radioactive waste production by:
   a. practicing ALARA
   b. having all your tools frisked after a job
   c. only bringing items you need to the job
   d. only using recyclable materials

Unit 5 Answers

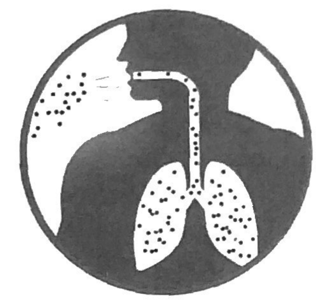
1. c	4. c
2. b	5. c
3. a, b, d	6. c

Unit 6: Personnel Monitoring

Once you complete this unit, you should be able to:

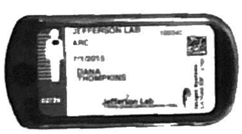
- list the pathways by which radioactive material can enter the body.
- explain why the Lab does not routinely monitor for internal contamination.
- recognize the purpose of and worker responsibility for each of the dosimeters used at Jefferson Lab.
- know how to respond to an alarming dosimeter.
- recognize your responsibility in reporting radiation dose you receive from other sites or medical applications.

Lesson 1: Internal and External Dose



In previous units we mentioned internal exposures several times. An uptake of radioactive material can cause dose to the whole body or individual organs. *Radioactive material can enter the body through inhalation, ingestion, absorption through the skin, or open wounds.*

Generally, internal depositions of radioactivity are the result of routine work involving high levels of surface contamination or accidents involving dispersible radioactive materials. For this reason, internal depositions of radioactive material at Jefferson Lab are extremely unlikely, and we do not require routine monitoring of workers. If needed, internal contamination can be assessed using whole-body counters and/or performing a urine or fecal matter bioassay (external dose is monitored through the use of personnel and supplemental dosimetry).

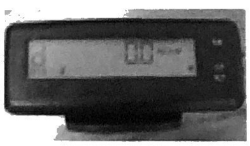


As already discussed, being around sources of radiation will lead to an external exposure, but this exposure can be kept ALARA through time minimization, distance maximization, and shielding. However, we are required by law to monitor your dose if it is likely to reach 100 mrem or more per year.

Lesson 2: Personnel Dosimetry

Dosimeters are radiation detection devices used to record the dose received by the wearer. The two types of dosimeters routinely used at JLab are the optically stimulated luminescent (or OSL) personnel dosimeter and an electronic self-reading pocket dosimeter. In addition, we sometimes issue ring dosimeters if high extremity doses are expected. *These devices do not provide any protection against radiation*; they just measure the amount of radiation to which you are exposed.

The personnel dosimeter is used to obtain your official dose of record. Personnel dosimeters are processed every six months, though your dosimeter may be retrieved for special processing more frequently if necessary. The personnel dosimeters used at Jefferson Lab are sensitive to beta, gamma, and neutron radiation.



The term **self-reading pocket dosimeter (SRPD)** applies to any of a variety of devices which can be read by the wearer to determine the dose received. An SRPD is normally used as a supplemental device to aid in dose tracking during activities where elevated doses are possible – it allows you to see your real-time dose accumulation. The electronic SRPDs used at JLab not only give you visual feedback on your real-time cumulative dose, but can alarm if you exceed your dose limit for a particular task or if the dose rate suddenly increases.

Immediately notify RadCon if your SRPD alarms, if you suspect that you have received a high dose, may be contaminated, or if you have lost, damaged or potentially compromised your dosimeter.

For irregular SRPD reading/alarm:
1. Secure work activities
2. Alert others in the area
3. Immediately exit the area
4. Contact RadCon

Personnel and supplemental dosimeters are issued by RadCon. You must complete a dosimeter request form, available on our web-site, and be Radiological Worker I qualified to receive a personnel dosimeter. If you are escorting a visitor into an RCA, you must bring the visitor by our office for issuance of a temporary dosimeter.

You must wear your personnel dosimeter whenever you enter an RCA, and when required by signs, work permits, or RadCon. We are interested in monitoring your whole-body dose; therefore, your dosimeter must be worn on the chest between the waist and neck or as directed in radiological procedures, radiological work permits (RWPs), or by RadCon. Wear the dosimeter with your name and information section facing forward. It should be attached such that it will not continually flip around or swing away from your body while you are working.

Your radiation exposure records are maintained by RadCon – you have the right to inspect your dose records at any time. You will automatically receive a report of your dose history annually, and if requested, upon termination of your employment or assignment at JLab. If you have questions about your dose or want to review your records, contact our Dosimetry Office.

It is important that we have an accurate record of your dose. You should notify the Dosimetry Office of:

- any occupational radiation exposures received before coming to Jefferson Lab.
- dose you receive while working at another facility while also employed by the Lab.
- termination of your employment or a change in your work responsibilities at the Lab.
- any medical administration of a radiopharmaceutical such as Tc-99m or I-131.

Remember, your dosimeter measures your radiation exposure only if it is with you when you are working. When you are not wearing your dosimeter, keep it in the assigned rack at the spot with your dosimeter number. *Do not take your Lab-issued dosimeter off site!* If you might receive a radiation dose at another facility, their staff will provide you with appropriate dosimetry.

Review Questions: Unit 6

1. Which types of radiation are measured by your personnel dosimeter?
   a. alpha, beta, and gamma
   b. beta, gamma, and neutron
   c. alpha, beta, and neutron
   d. alpha, gamma, and neutron

2. Where is the proper place to store your dosimeter when not in use?
   a. a locked safe
   b. your office
   c. a dosimeter rack
   d. your assigned dosimeter rack

3. In addition to the personnel dosimeter, supplemental dosimetry such as a(n) ________ may be used when elevated dose rates are present.
   a. TLD
   b. OSL
   c. SRPD
   d. GM

4. What is the main purpose for wearing a supplemental dosimeter?
   a. Allows the individual to receive radiation dose above the administrative control level
   b. Allows the individual to work in highly contaminated areas
   c. Allows the individual to work in the beam enclosure when beam is present
   d. Allows the individual to closely track your radiation dose when working in significantly elevated radiation levels

5. If your dosimeter has an irregular or unexpected reading, or it is sounding an alarm, you should:
   a. stop work, alert others in the area, exit immediately, and notify RadCon
   b. finish your work, leave the area, tell your supervisor, and notify RadCon
   c. stop work, exit immediately, alert your supervisor, and notify RadCon
   d. alert others, finish your work, leave the area, tell your supervisor

6. What function does a personnel dosimeter serve at Jefferson Lab?
   a. Measures your external radiation exposure
   b. Measure your internal radiation exposure
   c. Protects workers from excessive radiation exposure
   d. All of the above

7. Why doesn't the Lab's dosimetry program include routine internal monitoring?
   a. we don't have that capability
   b. the potential for any significant internal dose is extremely small
   c. an internal dose is not possible at JLab
   d. your personnel dosimeter can be used to monitor internal as well as external dose

8. What is your responsibility when you receive radiation dose at another facility while employed at Jefferson Lab?
   a. have your JLab dosimeter read immediately upon your return
   b. take your JLab dosimeter to the other facility and use it there
   c. notify RadCon upon returning to the Lab and follow their direction
   d. cease radiological work at JLab until your dose records arrive from the other facility

9. Any medical administration of radioactive material should be reported to (select all that apply):
   a. RadCon
   b. The Crew Chief
   c. Your supervisor
   d. Occupational Medicine

Unit 6 Answers

1. b
2. d
3. c
4. d
5. a
6. a
7. b
8. c
9. a

Unit 7: Sources of Radiation at Jefferson Lab

Upon completion of this unit, you will be able to:

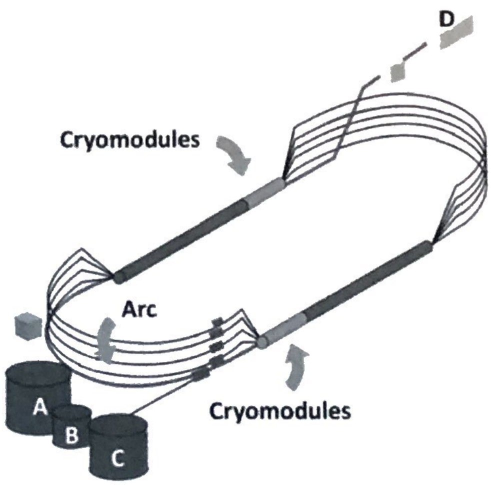
- define prompt and residual radiation
- state the locations where exposure to high dose rates is possible during beam operations
- give examples of commonly activated materials
- state the difference between activation and contamination
- give examples of non-accelerator sources of radiation
- explain the purpose and use of radiological surveys

Lesson 1: Radiation Sources

The largest source of radiation at Jefferson Lab is the CEBAF accelerator enclosure. In addition, radiation sources can be found in the LERF, the Test Lab, and the EEL buildings, as well as other locations within and beyond the accelerator site boundary.

High-energy accelerators, such as the ones found at the Lab, have the potential to produce high levels of radiation when the electron beam is on as well as the ability to produce radioactive material in the systems and surrounding structures of the beam enclosure.

Radiation in the beam enclosures can be broadly categorized as either prompt or residual.



Lesson 2: Prompt vs. Residual Radiation

Radiation resulting from the accelerator beam or the interaction of the beam with matter is called **prompt** or **primary radiation**. *Prompt radiation is produced only when the beam is operating*, and consists mainly of high-energy photons and neutron radiation.

Prompt radiation within the beam enclosure is the most intense radiation present at JLab. Direct exposure to a particle beam or a secondary radiation "shower" could result in a potentially dangerous and even lethal dose of radiation.

Interlocked access points provide a fail-safe barrier against direct beam exposure during operation. Additionally, the enclosures are well shielded by their underground design. However, there are a few locations where radiation levels can be elevated due to proximity to the beam enclosure. These include:

- areas above unshielded penetrations in accelerator service buildings,
- the roofs of operating end stations, and

- accessible shielded labyrinths in the vicinity of the beam enclosure.

Always consult RadCon, operational safety procedures, or the operations Crew Chief regarding requirements for working in these areas.

The interaction of a high-energy beam with matter can cause the formation of radioactive materials. This process is often referred to as **activation**. Activated materials at the Lab emit **residual radiation**; mostly as gamma-rays and beta particles. Many of these materials are short-lived and become stable within days or weeks of activation, but others require years to decay to stable nuclides.

Exposure to activated materials is a major contributor to worker dose at accelerators; important sources of activation are listed to the right. Other materials which may become activated are lubricants, cooling water, and air contained in spaces within the beam enclosure.

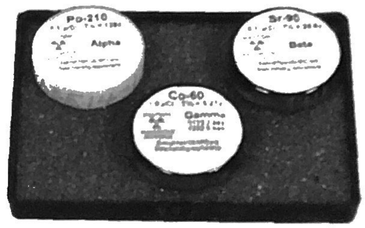
Commonly activated materials:
- Magnets
- Beam dumps and stops
- Beam-lines and beam-line components
- Targets
- Detectors
- Other experimental equipment

Lesson 3: Activation vs. Contamination

It is important to understand the difference between activated and contaminated material. **Contaminated materials** are items which either have removable surface contamination or contamination that is fixed to the surface but may be removed by abrasion or chemicals. Radioactive liquids are also a source of contamination.

Activated materials are radioactive, but do not have easily removable surface contamination. When handled properly, activated materials do not present a loose contamination hazard. They are usually controlled based on the external radiation dose rate. Activated materials can, however, become a source of contamination during activities such as:

- grinding or filing,
- burning or welding, and
- machining, cutting or drilling.



Any such modification to radioactive material, including beamline components and the structural components of the enclosure, requires RadCon approval.

Contamination can also occur due to the activation of materials which are inherently transferable, such as dust, rust, lubricants, and liquids. In addition, closed cooling systems associated with beam dumps are subject to a build-up of activation products that can present a radiation and contamination hazard during maintenance activities on these systems. Buildings or rooms which house cooling system components for high-power beam dumps may require special entry controls during beam operations.

Always obtain RadCon approval before working with any of these materials or systems.

Lesson 4: Non-accelerator Sources

There are other sources of radiation at Jefferson Lab in addition to accelerator-generated sources. Generally, they don't add significantly to personnel exposures. Small test sources or x-ray generators are used in experimental detector setups and for instrument calibrations and checks. These sources are controlled by a source custodian. To use these sources, you must be specifically approved by RadCon and the appropriate source custodian.

The radio-frequency or RF cavities used to accelerate the electron beam produced x-rays when operated; therefore, they may only be operated in shielded, interlocked enclosures. The cavities are tested in shielded enclosures in the Test Lab, where strict adherence to radiological safety practices is enforced.

Review Questions: Unit 7

1. Radiation at accelerators may be grouped into two broad categories:
   a. beta and gamma radiation
   b. gamma and neutron radiation
   c. prompt and residual radiation
   d. prompt and delayed radiation

2. Prompt radiation from the electron beam consists primarily of ________ radiation.
   a. beta and gamma
   b. gamma and neutron
   c. alpha and beta
   d. beta and neutron

3. Working around activated materials:
   a. involves little or no radiation exposure
   b. causes exposure to neutron radiation
   c. involves only beta exposure
   d. causes most of the whole-body gamma dose at JLab

4. When would you likely be exposed to prompt radiation?
   a. working in the accelerator tunnel after beam shutoff
   b. handling sealed radioactive sources
   c. working in a service building during beam operations
   d. working in an experimental hall after beam shutoff

5. Where is contamination likely to be found?
   a. in filings, dust, shavings, etc. produced from machining activated material
   b. in beam dump cooling water systems
   c. in surface coatings on activated beamline components
   d. all the above

6. Handling activated material such as magnets or other beamline components ________ usually requires contamination control measures.
   a. does
   b. does not

7. Use of sealed radioactive sources requires authorization by RadCon and permission from:
   a. DOE
   b. The on-duty Crew Chief
   c. The source custodian
   d. Both the Crew Chief and the Custodian

Unit 7 Answers

1. c
2. b
3. d
4. c
5. d
6. b
7. c

Unit 8: Radiation Controls

At the end of this unit, you will know the names, purposes, and operation of various controls as well as who is responsible for the controls.

Lesson 1: Responsibilities for Radiation Control & Safety

Safety is everyone's responsibility! However, the **Radiation Control Department** implements the requirements of the radiological control program. These requirements are established in DOE Orders and regulations, the TJNAF Radiological Control Manual, and site radiological control procedures.

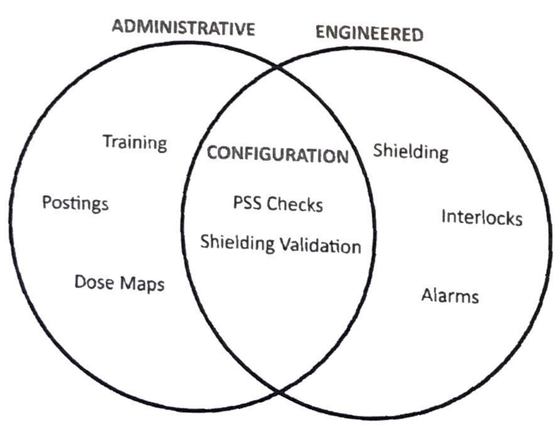
Radiological Control Technicians (RCTs) provide a point of contact between you, the radiological worker, and RadCon. Technicians provide the most current radiological conditions in an area; assist when interpreting protective requirements or radiological information concerning a work assignment; and, address radiological questions and concerns.

Accelerator operators and other designated individuals have received additional training in radiation safety and monitoring techniques. These people are designated as **Assigned Radiation Monitors** or **ARMs**. Tasks performed by ARMs that are of interest to radiological workers include:

- escorted surveys: performing surveys during brief accesses to the beam enclosure,
- surveying and assisting with disposition of equipment removed from the beam enclosure, and
- initial response to alarming radiation monitoring equipment or abnormal events.

Lesson 2: Types of Radiological Controls

Radiological controls can be grouped into two broad categories: engineered controls and administrative controls. At times, the two methodologies are implemented simultaneously.

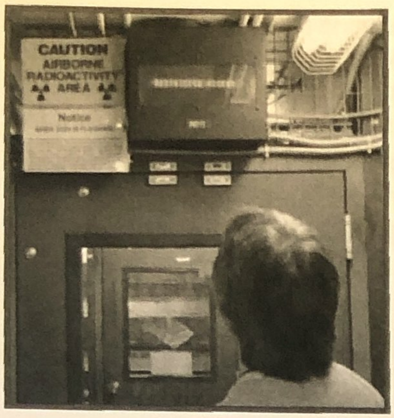


In general, **engineered controls** are the primary method used to ensure safety by reducing, eliminating, or preventing access to a hazard. These controls usually operate automatically.

Administrative controls are implemented through procedures and practices, and are an important tool in minimizing exposures.

Lesson 3: Engineered Controls

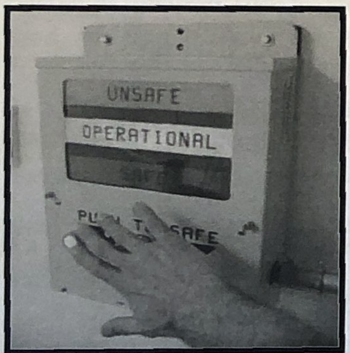
Protection from prompt radiation hazards is accomplished primarily by engineered controls such as the shielded beam enclosure, which limits the radiation levels in areas outside the shield, and the **personnel safety system (PSS)**, which is designed to prevent access to hazardous areas or prevent the hazards from occurring when personnel are present.



Accelerator status indicators are located at each primary entrance to an accelerator enclosure; they display the current accelerator mode. Worker access is allowed only during restricted or controlled access. During **restricted access**, all electron beam and related power sources are disabled, surveys for residual radioactivity have been done and postings have been established. Interlocked access controls are deactivated, access is permitted for workers who have met training and administrative requirements for entry. During **controlled access**, electron beam and related power sources are functional but interlocked. Positive access control is maintained through interlocked access controls. This process involves several redundant interlocks which prevent accelerator operation during access. Access to the accelerator enclosure is not allowed during **beam permit** and **power permit** accelerator modes.

After the initial entry radiation survey is complete, follow these steps to make a controlled access:

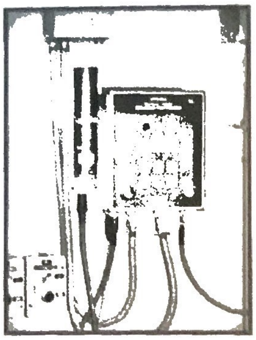
- <u>Call</u> the safety system operator (SSO) to request access
- <u>Enter</u> the first door when the door lock is released; the SSO will then release the master key.
- <u>Remove</u> the key and place it in the master position of the key bank, then remove a personnel key and show it (via the camera) to the SSO. *The key <u>must</u> remain in your possession at all times while you are in the beam enclosure.*
- <u>Provide</u> all requested information to the SSO and enter the enclosure when the inner door is released.



Run/safe boxes are interlock devices within the accelerator enclosure that provide a display of the safety system's general status as well as a means to deactivate or crash the interlock system to turn off the beam. When the accelerator is in restricted access, the interlock system is disabled and the run/safe boxes should display the green/safe light. Once the interlocks have been established, the only way to access the enclosure is to use the controlled access procedure. During controlled access, the boxes should display the operational and safe lights; the red unsafe light should never be displayed when the enclosure is accessible. *If the display is not correct for the access mode, immediately press the push to safe button, leave the enclosure, and call the Crew Chief.*

Another device used to indicate accelerator status is the **magenta beacon**. These beacons are located near secondary entrances to beam enclosures. These access points remain locked and interlocked at all times when the safety system is active. Access through these doors is permitted <u>only</u> when the accelerator is in the restricted access mode and the beacon is off. Magenta beacons are also used in other radiation protection systems. They are part of the radiation monitoring system that substitutes for access surveys in some areas, and are called rapid access monitors. You should become familiar with these systems if they are used in your work area.

Regardless of the system they are used with, magenta beacons have the same meaning: *hazardous radiation levels may be present and access is restricted*. However, they are not alarms and therefore are not cause for evacuation.



Controlled area radiation monitors, or **CARMs**, monitor occupied areas adjacent to interlocked beam enclosures. Like other components of the safety system, CARMs are designed to fail safe, and have redundant interlocks to the accelerator. CARMs automatically alert accelerator operators of increasing radiation levels, and will turn the beam off should radiation levels in an area increase above established set points. Should a CARM in your work area alarm, stop what you are doing, warn others to leave the area, notify the Crew Chief immediately, and provide requested information regarding instrument indications.

Design of the beam enclosure incorporates heavy use of shielding. The earth overburden on the beam enclosure is an obvious example. Such structures reduce the radiation levels in above ground buildings.

Temporary shielding, such as lead or concrete blocks, cannot be removed or altered without proper authorization. Temporary shielding will be marked or labeled with wording such as, *Controlled shielding configuration - Do Not Remove Without Permission from RadCon.*

Other components and devices used to limit radiation dose to workers and the environment include:
- radiation monitoring systems that provide warnings to workers, for example, the rapid access monitoring systems mentioned earlier
- systems that limit the production of radioactivity, such as the careful control of water chemistry in the beam dump cooling water
- ventilation and air filtration systems that control airborne radioactivity

The integrity and function of engineered controls are regularly checked to ensure proper operation.

Lesson 4: Administrative Controls

Administrative controls are used where radiation hazards are moderate or low. These controls rely on individuals to follow procedures and obey warning signs and alarms. Examples include:
- training that specifies practices and procedures which help minimize exposure;
- written procedures and permits such as radiological work permits; and,
- the use of postings that inform workers of the hazards and specify limitations and controls.

Radiological Work Permits (RWPs)

Radiological work permits are used to establish controls for entry into areas controlled for radiological purposes. RWPs serve to:
- inform workers of radiological conditions in the work area;
- inform workers of entry requirements and/or restrictions on work in the area; and,
- provide a means for dose tracking.

There are three types of Radiological Work Permits.

- The **General permit** is used to control routine or repetitive activities such as tours and inspections in areas with historically stable radiological conditions. No destructive modifications to radioactive materials or breaches of contaminated systems may be performed when using this type of permit. An example of such a permit is the *General Access RWP* which is required for entry to the beam enclosure. This permit is valid for one calendar year, and, as a radiological worker, you must read and sign it to gain access to the accelerator site.

- **Job-specific RWPs** are used to control non-routine operations or work in areas with changing radiological conditions. Job-specific permits are only valid for the duration of a particular job. Work on a contaminated object, for example, would require a Job-specific RWP.

- Some jobs, which would normally require a Job-specific RWP, occur repeatedly and are therefore, covered under a **Standing RWP**. Routine preventative maintenance work on a contaminated component, for example, may be covered under a Standing RWP.

• For routine, repetitive activities • Not for destructive or contamination work	• For non-routine work • Short term validity	• For re-occurring non-routine work

As a radiological worker, you must sign the General Access RWP once per year. This RWP covers all routine work in the beam enclosure, including incidental work in radiation areas, when concurrence from RadCon is given. In addition, you may need a Job-specific RWP to work in other areas your job takes you. Hardcopies of RWPs may be posted at the work site; electronic versions of RWPs are maintained online in the RWP database. You may access, read, and sign RWPs via the RadCon web page.

As a radiation worker, it is your responsibility to read, understand, agree to comply with the instructions on the RWP, and to complete the required training. Your signature acknowledges your agreement with the RWP. If a revision is made to an RWP you have already signed, you must review and sign it again.

If a job is to be performed in any of the following radiological areas, job supervisors should initiate an RWP via the RadCon homepage.

- high radiation or very high radiation
- contamination or high contamination
- airborne radioactivity

Likewise, if a job involves any other significant radiological hazard, an RWP should be initiated.

If you are unsure whether or not the work activity requires an RWP, consult with RadCon personnel. Once an RWP is initiated, RadCon will discuss the job specifics and radiological controls with the appropriate supervisor and write & complete the RWP for the job.

If necessary, RadCon technicians will survey the work area to determine the current dose rates and contamination levels. This information is then recorded on the RWP, or a separate survey map may be attached. Once RadCon staff complete the RWP, it is signed for approval by both the job supervisor and the RadCon Manager. The RWP is now ready for review and signature by all those who will perform activities covered by the RWP.

Radiological work permits include an accurate description of the proposed work, the building and room where the activity will be performed, as well as an assessment of the radiological and other hazards present. Dose and contamination control limits, pre-job briefing specifications, protective clothing requirements, and special engineering controls (ventilation, shielding, etc.) are also provided in the permit.

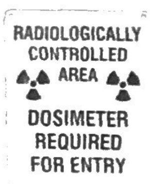
Along with RWPs, another set of important controls for radiation protection are **radiological postings** used to communicate radiological hazards in the workplace. The posting system uses signs with specific radiological designations and labeling. Postings are placed in plain view on walls, ropes, or doors at the entrances to the areas. *Do not enter radiological areas unless you have met the entry requirements.* If you are not sure whether you meet the requirements to enter a radiological area, contact your supervisor or RadCon.

Disregard for postings or other radiological instructions is grounds for disciplinary action.

Postings

A **controlled area** is any area where access is controlled in order to protect personnel from exposure to radiation or radioactive material. A controlled area may be defined by a barrier, such as a security fence, and may contain other buildings or labs within it. You will see other radiological postings, such as radioactive material area or radiation area, within a controlled area.

The potential radiological hazard in a controlled area is relatively low. Personnel entering only controlled areas are not expected to receive a dose of more than 100 mrem in a year. To enter a controlled area, you must be trained at least to the GERT level or be accompanied by an escort who is trained at least to the GERT level.



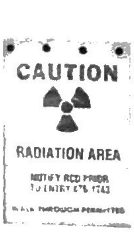
A **radiologically controlled area** (RCA) is an intermediate area where an individual's dose may exceed 100 mrem (typically greater than 0.05 mrem/h) if they spend their entire year working within the RCA. Such radiation levels are high enough that we require you to wear dosimetry to monitor your dose. Only Radiological Worker I-trained individuals are allowed to enter an RCA without an escort.

All RCAs are identified by signs that have the standard radiation symbol in magenta or black on a yellow background. In the absence of doors or other physical entry points, yellow and magenta rope, tape, chains, or markings are used to designate the boundaries of posted areas.

If you are escorting a visitor into an RCA, be sure to arrange for temporary dosimetry (through RadCon) for the visitor. As their escort, you must maintain visual and verbal communications with them while in the RCA.

Before leaving an RCA, ensure you have not left any waste items, tools, and personal belongings behind. Check to make sure you still have your personal dosimeter; and, if you are wearing an SRPD, read it so you know how much dose you received while in the area.

Within a radiologically controlled area, various other radiological postings may exist. These areas are usually defined by specific levels of radiation or contamination that may be present within.



A **radiation area** is an area where the whole-body dose rate is greater than 5 mrem/h. The whole-body dose rate is measured at 30 cm from the radiation source. Such areas are clearly marked by a boundary rope and a sign that reads **Caution, Radiation Area**. The source could be radioactive material or a radiation-generating device. As a radiological worker, you may enter such areas if all other requirements on the posting have been met. In addition, all the requirements for working in an RCA apply in a radiation area. You should be aware of the dose rates in the specific location you are working in and always try to position yourself in such a way as to minimize your dose.

For radiation areas, keep these general rules in mind.

- <u>Only</u> radiological workers are allowed in radiation areas - *do not escort visitors into radiation areas!*
- <u>An RWP is required</u> – although the General Access RWP may suffice, always check with RadCon.
- At a minimum, <u>RadCon concurrence</u> is required for you to work in a radiation area.

Radiation areas are found within RCAs. Some typical locations are near activated beam-line components in the accelerator tunnel and end stations, and above accessible penetrations in some service buildings.

Occasionally, a radiation area will completely block a passage way. If a Radiation Area sign contains the insert **walk through permitted**, you may cross the area to reach the other side without contacting RadCon. However, if you plan to work within the radiation area all the usual rules apply!

High radiation areas are clearly marked with boundaries and signs reading **Danger, High Radiation Area**. High radiation areas have whole-body dose rates of above 100 mrem/h. As an RW-I-qualified staff member, you are allowed access to high radiation areas if all the requirements for entry have been met. If the dose rate exceeds 1000 mrem/h, either a physical access control or a guard known as a *High Radiation Area Watch* will prevent you from inadvertently accessing the area.

High radiation areas may be found within RCAs. Some typical locations where you might encounter high radiation areas are:

- near irradiated high-power beam dumps,
- near highly activated portions of the beam line,
- in end station beam dump cooling water buildings,
- within interlocked beam enclosures while the beam is on,
- near operating RF accelerator cavities, and
- above unshielded penetrations in some service buildings

A **radioactive material area (RMA)** is an area where sealed sources or properly contained/non-dispersible radioactive material may be used or stored. This includes equipment, components, or materials that have been exposed to contamination or have been activated, as well as dispersible radioactive material in a tightly sealed container.

Individual objects within an RMA are not always tagged as being radioactive, so always get concurrence from RadCon prior to disassembling or removing such objects and equipment. This is particularly important when removing materials from beam enclosures.

You should also know that the presence of radioactive materials does not always signify that there will be elevated dose rates present. Radiological areas, such as radiation areas, are posted based on the potential for radiation exposure above certain levels, while radioactive material areas are posted based on the quantity of radioactive material present.

Radioactive material areas are found all over the Jefferson Lab campus. The entire beam enclosure, for example, is both an RCA and an RMA.

Remember, no food, drink, cigarettes, etc. are allowed in radioactive material areas or radiological areas such as radiation and high radiation areas. This not only prevents you from accidentally ingesting radioactive material, but is a way to practice good hygiene and prevent food wastes from being generated in radiological areas.

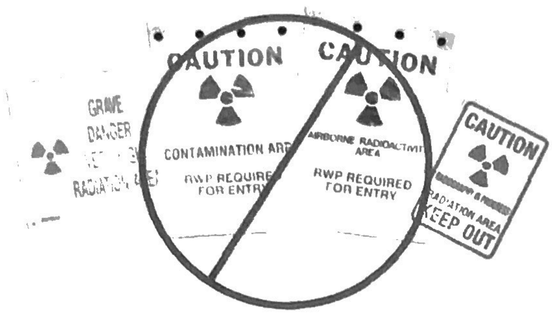
RadCon regularly conducts radioactive material inventories and ensures that levels are maintained below management-established control levels. Radioactive material purchasing, shipping, and movement on site can only be conducted with RadCon approval. In addition, radioactive material may never be transferred in non-DOE or personal vehicles.

A **hot spot** is a small spot where the contact dose rate is greater than 100 mrem/h and at least five times the dose rate at 30 cm. Hot spots are typically found on activated portions of the beam line and beam line components. *Never handle a hot spot without RadCon concurrence!*

As an RW-I qualified worker, there are some areas you *are not allowed to enter,* including

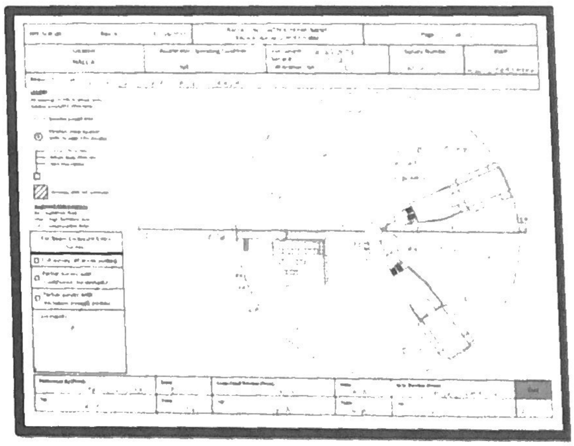
- very high radiation areas,
- contamination areas,
- airborne radioactivity areas, and
- radiography areas.

Do NOT enter these areas, they require RW-II training!



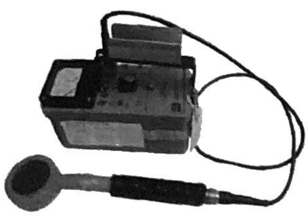
Dose rates in **very high radiation areas** are extremely high and require special controls for entry. **Radiography areas** can only be accessed by RadCon personnel and the radiographic team. To enter **contamination areas** and some **airborne radioactivity areas** you will need Radiological Worker Level II training. *If you do not have such training, you cannot enter these areas except in emergency situations.*

Other Administrative Controls



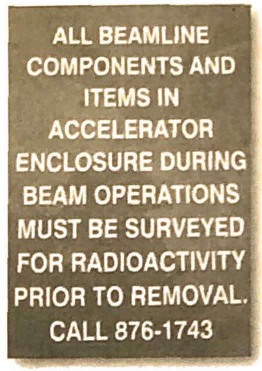
The posting and labeling of areas and materials discussed in this lesson are conducted by RadCon personnel. Our RCTs and ARMs regularly perform **radiation surveys** to identify areas with significant activation or contamination. The boundary locations for radiological areas are based on these surveys, data of which is documented on special maps that are posted at the main access points to the beam enclosure. You should get in the habit of reviewing the survey maps to become familiar with the dose rates in the areas where you work.

Radiological control operating procedures (RCOPs) define the scope and limitations to a task or procedure. They are used for handling certain radioactive sources, operating radiation-producing machines, and to establish hold points for experimental set-ups or first-time activities.



Friskers are instruments used to monitor for contamination after work in a contaminated or potentially contaminated area. As an RW-I qualified individual, it is unlikely that you will be required to frisk yourself.

Radioactive Material Control



All tools, equipment, components, or structural material present in the beam enclosure are subject to becoming activated and ***must be monitored prior to removal from the enclosure***. Only RadCon personnel may approve the release of material from the beam enclosure. There are staging areas where items requiring a survey can be stored.

Also, never move radioactive items from one area to another as this changes the dose rates in both locations and may require RadCon to redefine the area boundaries. If you need to move or remove materials, *contact RadCon*.

Waste Minimization

It is important that we all try to minimize the amount of radioactive waste produced at Jefferson Lab. Some easy ways to accomplish this include:

- Bring only the tools and materials you need into an RCA
- Unpack your equipment and tools in a clean area to avoid bringing excess materials into the RCA
- Segregate radioactive from non-radioactive wastes - special yellow and black bins located within the beam enclosure can be used to dispose of known or suspected radioactive materials. Materials known to be clean must be placed in waste bins designated for clean items.
- Use good housekeeping techniques.
- Do not generate mixed wastes – materials that can be classified as both radioactive and chemically hazardous. *For guidance, contact RadCon.*

It is your responsibility to read and comply with all radiological postings, RWPs, verbal instructions, and alarms. *Never* relocate or remove boundaries or signs. *Do not* reach across boundaries. If you find radioactive material outside an area controlled for radiological purposes or find anything else amiss, contact RadCon immediately. Disregard for any posting or instruction can lead to:

- personal liability
- disciplinary action
- loss of job
- shutdown of work site or facility
- injury
- equipment damage
- excessive, unnecessary, or even lethal exposure
- contamination

Whenever you work in a posted area, remember to always practice ALARA, know your evacuation points in case of an emergency, and immediately report any unexpected, dangerous, or alarming conditions.

Review Questions: Unit 8

1. CARMs monitor radiation levels in:
   a. the interlocked beam enclosure
   b. occupied areas near the beam enclosure
   c. the EEL building
   d. radioactive materials storage areas

2. If a CARM alarms, workers in the area should:
   a. ignore it, since the Crew Chief already knows something is wrong
   b. stop work, warn others, leave the area, and then notify the Crew Chief
   c. call RadCon ASAP
   d. hit the "acknowledge" button so the beam can be turned back on

3. The rotating magenta beacon:
   a. is not an alarm; it alerts personnel to the existence of high radiation levels
   b. is a radiological emergency alarm; it alerts personnel to the existence of high radiation levels
   c. is an ODH alarm; it signifies that personnel should leave the area immediately
   d. is an alarm indicating the use of high powered magnets; it alerts personnel to stay away from the area

4. An area posted as a **Radiation Area** has dose rates greater than ____ mrem/hr.
   a. 5
   b. 100
   c. 1000
   d. 0

5. Why is the beam enclosure posted as a **Radioactive Materials Area**?
   a. Because all JLab radioactive materials are stored there.
   b. It is not posted as a Radioactive Materials Area.
   c. Because no radioactive material can be brought into the beam enclosure.
   d. Because of the buildup of activated material in the components of the enclosure.

6. When removing material from the beam enclosure, it must be monitored for radiation if:
   a. it is part of the beamline.
   b. it was near a beam dump.
   c. it is made of steel.
   d. it was in the enclosure during beam operation.

7. A **Radiation Area**______requires an RWP.
   a. always
   b. sometimes
   c. never

8. When moving a component that is known to be radioactive from one location to another, even within an RCA, you should notify RadCon because:
   a. Depending on the radiaton levels, you may be creating a "moving radiation area" that must be properly posted. Also, the placement of the material near the boundary of a radiation area or RCA may impact the radiation level outside of the area.
   b. As long as the material stays in the beam enclosure, RadCon does not need to be notified.
   c. Because you may cause the spread of contamination.
   d. Every item in the enclosure is tracked by RadCon.

9. Entry to a **High Radiation Area** requires:
   a. Radiation Worker II training, an RWP, and a dosimeter.
   b. Radiation Worker II training, an RWP, a supplemental dosimeter, and a personnel dosimeter.
   c. Radiation Worker I training, an RWP, a supplemental dosimeter, and a personnel dosimeter.
   d. Radiation Worker I training, an RWP, and protective clothing.

10. Area designations such as **Radiation Area** and **High Radiation Area** are based on radiation dose rates measured ________ from the source of radiation. This measurement is known as a _______ dose rate.
   a. on contact, whole body
   b. on contact, measured
   c. at 30 cm (1 ft), whole body
   d. at 1 m (3 ft), measured

11. Radiation Worker I-trained individuals may not enter areas posted as:
   a. Radiation Area, High Radiation Area, Very High Radiation Area
   b. High Radiation Area, Very High Radiation Area, Contamination Area
   c. Very High Radiation Area, Contamination Area, Airborne Radioactivity Area
   d. Very High Radiation Area, Contamination Area, Radioactive Materials Area

12. Radiological work permits are used to inform you of ________ in an area, and to make you aware of ________ for entry. They also serve as a mechanism for ________ dose.
   a. dose rates, requirements, tracking
   b. hazards, requirements, measuring
   c. personnel, certifications, acquiring
   d. activity level, postings, tracking

13. The three types of RWPs implemented at Jefferson Lab are:
   a. standing, job-specific, and general access
   b. standing, generic, and job-related
   c. periodic, one-time, and continuous
   d. yearly, daily, and hourly

14. In the case of a Job-specific RWP, what two groups are typically involved in initiating the permit?
   a. The supervisor of those doing the work and RadCon
   b. Accelerator Operations and the supervisor of those doing the work
   c. RadCon's DOE counterpart and RadCon
   d. The ES&H Division and the supervisor of those doing the work

15. The following information may be found on an RWP (select all that apply):
    a. dosimetry requirements
    b. protective clothing requirements
    c. first aid measures
    d. stay time limits
    e. nature of the work
    f. radiological job coverage requirements

16. An RWP is always required in which area(s) (select all that apply)?
    a. radiation area
    b. controlled area
    c. high radiation area
    d. all of the above

17. Your signature on an RWP indicates that you have_____the RWP, that you _____it, and will follow the _______in it.
    a. seen, read, signature
    b. read, understand, requirements
    c. signed, read, terms
    d. skimmed, understand, instructions
    e. completed, signed, flowchart

18. Why is it particularly important that people closely follow RWP requirements?
    a. so JLab won't be sued if someone gets hurt
    b. because there are potentially lethal conditions in areas covered by RWPs
    c. because failure to do so could cause major damage to accelerator components
    d. because RWPs can minimize the radiological hazards to personnel by controlling activities in the area

19. You can help minimize the generation of radioactive waste by which of the following?
    a. Take only the tools and materials you need into the beam enclosure.
    b. Practice good housekeeping.
    c. Unpack materials outside the beam enclosure and dispose of the packing material.
    d. Don't place "clean" material in a radioactive waste container.
    e. All of the above

20. Where can you get information about the radiation levels in your work area?
    a. Radiological survey maps
    b. An RCD Technician
    c. Radiological work permits
    d. All of the above
    e. None of the above

21. To remove an item from the beam enclosure that was there during beam operations
    a. it must be tested for tritium by Industrial Hygiene
    b. it must be surveyed by RadCon
    c. no special precautions are required, as long as it was not part of the beamline
    d. you must first scan it with a contamination monitor

22. The main reason for performing a radiation survey after beam operations is
    a. radiation surveys are not required after beam operations
    b. because high levels of airborne radioactivity may exist
    c. to ensure that the beam does not come on while personnel are in the enclosure
    d. to determine the levels of exposure and establish controls based on these levels

Unit 8 Answers

1. b
2. b
3. a
4. a
5. d
6. d
7. a
8. a
9. c
10. c
11. c
12. a
13. a
14. a
15. a, b, d, e, and f
16. a and c
17. b
18. d
19. e
20. d
21. b
22. d

Unit 9: Emergency Response

This unit will show you the steps to follow in a beam-on emergency, a medical emergency, and if you encounter a spill.

Lesson 1: Precautionary Measures

Working in a radiological environment requires more precautionary measures than performing the same job in a non-radiological environment. This premise is especially true if an emergency arises during radiological work. Radiological emergencies include improper status indicators or change of status on Run/Safe boxes; fire in a radiological area; high radiation exposures to personnel; injury or loss of life in a radiological area; and, damage, abuse, or loss of radioactive material or sources.

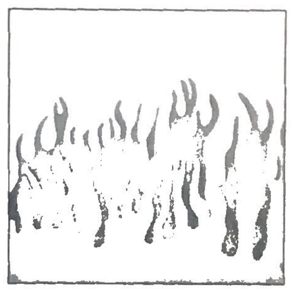
If you discover a radiological emergency, the responsibility for dealing with it initially rests with you! Take appropriate actions to protect life, property, and the environment. Warn others in the area of the situation and minimize your own radiation exposure. Finally, make appropriate notifications.

In extremely rare cases, emergency exposure to high levels of radiation may be necessary to rescue personnel or protect property. In these cases, offsite emergency responders in charge will guide the operation using careful judgment due to the substantial risk to personnel. The official's judgment is guided by many variables that include determining the risk versus the benefit of an action and deciding how best to implement the action.

Radiological workers who volunteer to perform **lifesaving operations** must be thoroughly informed of the hazards, and must be trained and qualified to work under such conditions. The DOE maintains emergency dose limit guidelines for these types of situations.

Lesson 2: Fires and Tornados

If a **fire alarm** sounds while you are in a radiological area, evacuate immediately! Even if you are wearing protective clothing and are normally required to be surveyed for contamination upon leaving the area, evacuate and quickly go to the muster point. Once there, keep away from others and wait until further directions are received from RadCon and an "All Clear" is announced.



If a **tornado alarm** sounds while you are in a radiological area, *<u>you must evacuate immediately</u>*. Even if you are wearing protective clothing and are normally required to be surveyed for contamination upon leaving the area, evacuate! Quickly go to the closest severe wind "Take Cover" area and stay put. Once at the muster point, keep away from others and wait until further directions are received from RadCon and an "All Clear" is announced.

Lesson 3: Beam-on Emergency

A **beam-on emergency** is one of the worst-case scenarios for an accident that could occur at Jefferson Lab. An individual who is in the beam enclosure during beam operations can receive a very high, possibly lethal, radiation dose. If you ever find yourself in the accelerator tunnel or in one of the halls while the beam is on, follow these steps:

1. **Stop work** immediately and press the red button on the nearest Run/Safe box. This should turn the beam off and change the status from unsafe (red) **to** safe (green). Make a mental note of your location and immediately exit the area via the nearest exit. Be sure to inform others of the situation and have them evacuate as well.

2. **Seek** immediate **medical attention** – call 911 – if anyone is injured. An injured individual who is not conscious or ambulatory should only be moved by medical personnel – *<u>do not try to move them</u>*. Provide any information you know regarding the radiological conditions to the emergency services contact.

3. The Crew Chief has overall responsibility for safety and coordinating an emergency response on the accelerator site. **Contact the Crew Chief (757-269-7045** or **757-630-7050)**, explain what occurred, and any actions you have taken. The Crew Chief may request that an ARM be allowed to perform a radiation survey on your person or may request that you allow a survey of certain articles, such as loose change, on your person. Complying with such a request will provide important information regarding your potential radiation exposure.

4. **Remain in the location designated by the Crew Chief** until RadCon personnel can determine the extent of your potential exposure.

Lesson 4: Medical Emergency

If an injury occurs in a radiological area, the recommended response depends on the nature of the injury. For cuts or wounds, the victim should move away from high-level sources of radiation and potential sources of radioactive contamination. However, if there is a chance that moving the victim could result in greater injury (for example a spinal injury), *DO NOT attempt to move the person unless there is another eminent threat to their life such as a fire or an electrocution hazard.* The health risks from the radiation exposure are relatively small and aid during life threatening injuries takes precedence over radiological protection concerns.

Call 911. You should also **contact TJNAF security** by dialing 5822. This will allow them to notify other JSA members (such as RadCon) whose assistance you may need; and, allow medical personnel quick escort to the accident site.

If you are capable, **provide aid** to the injured party, regardless of where the accident has occurred. For example, you may enter a contamination area to perform cardiopulmonary resuscitation (CPR). Once emergency personnel arrive, move aside and allow them to do their job. However, wait for RadCon to brief you on the accident and check you for potential contamination before leaving the scene.

Lesson 5: Spills

In the event of a spill or loss of radioactive material, a potential excessive or unmonitored exposure, or a spread of contamination to personnel or uncontrolled areas, contact RadCon immediately. All Lab phones have a tag attached to them with emergency contact phone numbers.

If you discover a spill of potentially radioactive material, remember the acronym **SWIMN**:

Stop spill if possible
Warn others in the area
Isolate the area
Minimize exposure
Notify the RCD (RadCon)

1. **S**top the spill – upright an overturned container, for example, that is causing a spill.
2. **W**arn others – make sure people in the area know what has happened.
3. **I**solate the area – close doors or use convenient items, such as chairs or waste bins, to form a barrier around the spill.
4. **M**inimize your own exposure – once you have taken the initial steps, move away from the area.
5. **N**otify RadCon and follow their instructions.

Review Questions: Unit 9

1. How would someone know they are in the beam enclosure during potential beam-on conditions?
   a. Run/Safe box with a yellow light
   b. Run/Safe box with a red light
   c. A loud hissing sound
   d. A flashing blue light

2. The worst-case radiation accident scenario at JLab is a direct, beam-on exposure to someone in the tunnel. What is the potential impact of such an accident?
   a. Exposure to RF radiation
   b. A lethal radiation dose
   c. An ODH emergency
   d. Inhalation of ozone and other poisonous gases

3. In the case of a direct beam exposure, the first notification should be to:
   a. RadCon
   b. On-duty Crew Chief
   c. Security Guards (x5822)
   d. DOE Safety Officer
   e. ES&H Director

4. If a person is in a high radiation area and experiences a severe traumatic injury, the primary concern ALL by-standers, safety professionals, and rescue personnel should be:
   a. immediate evacuation of the area
   b. moving the injured party to a safe location and calling for help
   c. attending to the injury, i.e., lifesaving measures, stabilization of the person's condition, etc.
   d. waiting for further instructions from RadCon

5. If you encounter a spill of contaminated water, you should:
   a. try to stop the spill without making the situation worse
   b. warn others in the area to stay away from the spill
   c. isolate the area, call RadCon, and await their arrival at a safe distance
   d. all of the above

Unit 9 Answers

1. b
2. b
3. b
4. c
5. d

Attachment 1: Radiation Terms

acute dose: a large dose of 10 rad or more to the whole body, delivered during a short period of time (on the order of a few days at the most)

administrative control(s): implemented through procedures and practices

as low as reasonably achievable (ALARA): making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical

average background dose: on average, if you live in the United States, you will receive 620 mrem per year of background radiation from both natural and man-made sources

Becquerel (Bq): one disintegration per second used for quantifying radioactivity

chronic dose: relatively small amount of radiation received over a long period of time

declared pregnant worker: DOE policy states that a female Radiological Worker should be encouraged to voluntarily notify her employer, in writing, when they are pregnant

disintegrations per minute (DPM): is a unit of activity that is often used when quantifying surface contamination

engineered control(s): primary method used to ensure safety – eliminating or preventing access to a hazard – usually operate automatically

rem: the special unit for measuring dose in a person, called the equivalent dose

removing material from beam enclosure: to remove an item from the beam enclosure that was there during beam operations – *it must be surveyed by RadCon*

whole body: extending from the top of the head down to just below the elbows and just below the knees

Attachment 2: Review Tables

Table 1. Radiation types of interest and properties

	Alpha (α)	Beta (β)	Gamma (γ)	Neutron (η)
Penetrating Distance	1 inch	~10 feet	n/a	n/a
Good Shielding	• paper • skin	• aluminum • wood • plastic • glass (not lead)	• lead • concrete • steel	• water • poly – thermal • lead & steel – fast
Hazard	internal	shallow	whole body	whole body
Rank in Terms of Penetration *(1 being most penetrating)*	4	3	1	2

Table 2. Dose limits for workers and the general public

	DOE Limits	TJNAF Administrative Control Limits
Whole body	5 rem/y	1 rem/y
General public	100 mrem/y	50 mrem/y
Pregnant worker (declared)	500 mrem per pregnancy	n/a
Minors working at the Lab	100 mrem/y	50 mrem/y

Table 3. Controlled and radiological areas summary

Area	Dose Rates	Access Requirements
Controlled Area (CA)	< 100 mrem/y	GERT trained or have an escort
Radiologically Controlled Area (RCA)	> 0.05 mrem/h and < 5 mrem/h as measured 30 cm from the source	- Dosimeter - RW-I - General Access RWP - must escort visitors with dosimetry (SRPD will suffice)
Radiation Area (RA)	> 5 mrem/h to < 100 mrem/h as measured 30 cm from the source	- RW-I - General Access RWP - Dosimeter - RadCon approval - NO VISITORS are ALLOWED in an RA
High Radiation Area (HRA)	> 100 mrem/h	- RW-I - General Access RWP - supplemental dosimeter - Job-specific RWP - Dosimeter - RadCon approval - NO VISITORS are ALLOWED in an HRA
Radioactive Materials Area (RMA)	area where access to RAM exists	- GERT for entry (RMAs are within controlled areas) - if handling RAM • RW-I qualified • dosimeter
Very High Radiation Area	500 rads/h at 1 meter from a radiation source <u>or</u> from any surface that the radiation penetrates	*Special controls for entry -- contact RadCon*