

# **RADIATION WORKER I TRAINING**

## **STUDY GUIDE**

**Jefferson Lab Radiation Control Department  
Revision 2.0, May 2010**

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## COURSE OVERVIEW

Radiation Worker I training is required if your job duties are such that you will make routine entries into TJNAF Radiologically Controlled Areas. The training is provided to help ensure your safety and the safety of your co-workers. Should you have any questions relating to radiological safety, don't hesitate to ask your instructor or any member of the Radiation Control Department (RCD) at any time.

## HOW TO USE THIS STUDY GUIDE

This study guide is used as the course handout during the full 8 hour classroom presentation of Radiation Worker I Training. This class is recommended if you have never been trained in the any aspects of radiation safety. If you attend the course, follow along in the handout, work through the review questions, and ask your instructor questions during the course, you should be well prepared to take the required Radiation Worker I written exam and do the practical factors exercise.

If you have previous training as a Radiation Worker, or wish to "challenge" the classroom portion of the material, you may use this guide as a self-paced review of the classroom material or use our interactive web-based training (<http://www.jlab.org/accel/RadCon/training.html>). After reviewing the material, you may attend the written exam and practical factors exercise to obtain credit for the class.

In either case, you must satisfactorily complete the written test and practical exercise to receive credit for Radiation Worker I Training.

You must complete the written exam and practical portion with a minimum score of 75%. Questions on the exam will come from the learning objectives in this handout.

Included in the information in this handout are review questions. Answers for these questions are provided at the end of each topical section.

Items in bold type are particularly important and/or related to the training objectives.

If you come to a term that you are not familiar with, refer to the glossary at the back of this handout.

You may keep this handout for future reference.

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## 1 Introduction

Welcome to Radiation Worker I Training (RWT). The purpose of this training is to ensure that you have the necessary knowledge and skills needed to work safely in radiological areas.

RWT is required for personnel who must make unescorted entries into radiological areas at TJNAF. When you have completed RWT you will:

- Be qualified to enter and work in Controlled Areas and some radiological areas at TJNAF.
- Be qualified to escort visitors within the site Controlled Area (and Radiologically Controlled Areas when proper dosimetry procedures are followed).
- Be qualified in all aspects of Radiological Worker I training common to all DOE sites.
- *Note: You must receive site-specific training to be fully qualified at another DOE site.*

**Retraining on RWT is required every two years.** To re-qualify on RWT, or to transfer your RWT qualification from another DOE facility, you may follow the “self-paced study” method outlined on the previous page.

## 2 Objectives

On the written exam and practical factors exercise, you will need to demonstrate knowledge of the following by selecting from a group of responses:

1. The definitions of ionizing radiation, radioactive material, radioactive contamination, radioactivity, radioactive half-life, and ionization.
2. The three basic particles of an atom.
3. The four basic types of ionizing radiation, and the following characteristics for each type:
  - a. Physical Characteristics
  - b. Range/shielding
  - c. Biological Hazard(s)
4. The units used to measure radiation and radioactivity.
5. Convert rem to millirem and millirem to rem.
6. Distinguish between ionizing radiation and non-ionizing radiation.
7. The possible effects of radiation on cells.
8. The mechanism by which radiation damages biological tissues.
9. The definition of the terms acute dose, chronic dose, somatic effect, and heritable effect.
10. The dose range for various effects of the acute radiation syndrome.
11. The LD<sub>50</sub>/30 dose
12. The potential effects and relative risks associated with prenatal radiation doses.
13. Compare the biological risks from chronic radiation doses to health risks workers are subjected to in industry and daily life.
14. The average annual dose to the general population from natural background and man-made sources.
15. The major sources of natural background and man-made radiation.

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16. The responsibilities of the Radiation Control Department.
17. DOE dose limits and guidelines, including emergency exposure guidelines.
18. Your responsibility in complying with DOE dose limits and TJNAF administrative control levels.
19. The actions you should take if you suspect that dose limits or administrative control levels are being approached or exceeded.
20. The DOE/Site management policy and the purpose of the ALARA program.
21. The responsibilities of Management, RCD personnel and the Radiation Worker in the ALARA program.
22. The three basic protective principles of ALARA.
23. Methods for reducing external and internal radiation exposure.
24. Ways radioactive material can enter the body.
25. How dose from internal radioactivity is determined.
26. How external radiation dose is determined.
27. The colors and symbols used on radiological postings, signs and labels.
28. TJNAF administrative dose limits for the whole body.
29. The site policy concerning prenatal radiation exposure.
30. How to obtain your radiation dose records, and your responsibilities for reporting radiation dose received from other sites and from medical applications.
31. The proper use of each type of dosimeter.
32. Site-specific dose reduction methods.
33. The definitions of prompt radiation and activation.
34. Major sources of prompt radiation and activation as well as ancillary radiation sources on site.
35. The purpose of initial entry surveys.
36. Requirements for removing material from the beam enclosure.
37. The main types of engineered and administrative radiological controls, and the elements of the configuration control program.
38. The function of the access control system (Personnel Safety System), including the status indicators and displays associated with the various modes.
39. The purpose of and information found in Radiological Work Permits (RWPs) and your responsibility for the correct use of RWPs.
40. The definitions of Controlled Area, Radioactive Materials Area, RCA, Radiation Area, and High Radiation Area.
41. Requirements for entering, working in, and exiting the areas listed in 40.
42. Radiological areas which you are prohibited from entering, and the postings for each area.
43. The purpose and use of personnel contamination monitors.
44. The appropriate response to contamination monitor alarms.
45. The purpose and types of emergency alarms or status indicators used at TJNAF and the correct responses in the event of an emergency or alarm.
46. The possible consequences for disregarding radiological postings, instructions, alarms and/or status indicators.

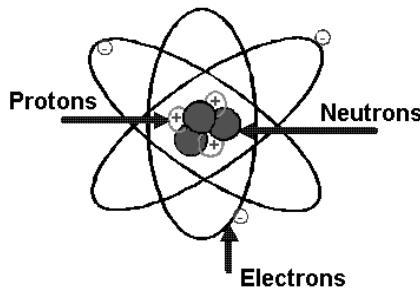
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## 3 Radiological Fundamentals

### 3.1 Atoms and Radiation

The elements that make up all matter are composed of atoms. Each atom is made up of three major parts that help form the atom's physical and chemical properties. The three basic particles are:



**Proton** - positive charge, in the nucleus.

**Neutron** - neutral (no) charge, in the nucleus.

**Electron** - negative charge, orbits the nucleus.

Atoms may be referred to as *stable* or *unstable*.

Stable atoms do not contain excess energy.

Unstable atoms contain excess energy. This is caused by an imbalance in the ratio of protons to neutrons in the nucleus of the atom. Unstable atoms release their excess energy during the process known as radioactive decay. The energy released in the process is called ionizing radiation.

**Ionizing radiation** is energy in the form of waves (rays) or particles which can penetrate matter and cause ionization.

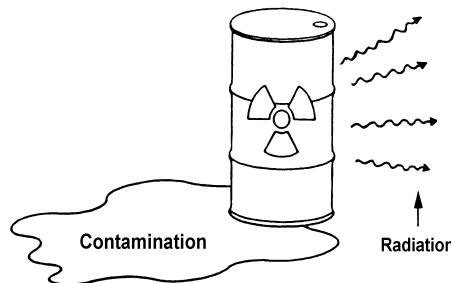
**Radioactive Material** is any material which contains unstable atoms that emit ionizing radiation.

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## 3.2 Radiation vs. Contamination

Radioactive material may exist in any physical form, such as solids or liquids. Any radioactive material which is easily spread or has been transferred to surfaces, liquids, or the atmosphere is known as radioactive contamination. Contamination is a concern due to the potential for its spread to personnel.



A simple definition for **contamination**: radioactive material in an unwanted place.

Radiation is emitted from any radioactive material, including contamination. In addition, radiation may be created through certain physical processes, such as those used in x-ray machines. The operation of the electron accelerator at TJNAF involves such processes. Due to the high energy nature of TJNAF's beam, it can also cause the formation of radioactive material (**activation**). This material is produced in and among the components of the accelerator.

If you are not familiar with working around radiation or radioactive material, the terms and concepts may confuse you at first. Let's look at the terms we discussed above in more detail.

**Radiation** - Radiation is energy in the form of waves or particles given off during radioactive decay, or as a consequence of certain physical processes that we can control. Examples of these are x-ray machines and particle accelerators.

- Wave radiations include gamma- and x-rays. A common term used to describe this type of radiation is photon radiation.
- Particle radiation can consist of charged or uncharged particles which are emitted with very high velocity.

Radiation travels from its source at very high speeds, and depending on the type, may be able to penetrate easily through very dense materials.

**Radioactive material** - Any material that contains radioactive (unstable) atoms. Radioactive materials are everywhere. Usually, we only encounter them in very small amounts. Since radioactive material contains unstable atoms, it emits radiation.

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**Radioactive contamination** - Not all radioactive material is considered "contamination". Contamination is radioactive material that has been spread to unwanted locations. Many radioactive sources are sealed or are in a form that isolates the material from potential spread. Contamination may be fixed, transferable (loose), or airborne.

It is important to note that exposure to radiation does not result in contamination (or activation) of the worker. You may become contaminated only through direct contact with removable radioactive material, or by working in areas where this contaminated material is handled.

**Radioactivity** - Radioactivity is the process of unstable (or radioactive) atoms becoming stable by emitting radiation. The radioactive decay process involves fundamental physical constants which enable us to characterize and measure radioactive materials very accurately.

**Radioactive half-life** - Radioactive half-life is the time it takes for one half of the radioactive atoms present in a given sample to decay. The half-life of a particular radionuclide is a constant, and depending on the radionuclide, it may range from a fraction of a second to millions of years. After seven half-lives the activity will be less than 1% of the original activity.

**Ionization** - The process of ionization is important in understanding radiation, because it is this process that differentiates ionizing radiation from other types of radiation such as microwaves and UV light. Ionization is the process of removing electrons from atoms. If enough energy is supplied to remove electrons from the atom the remaining atom has a + charge. The positively charged atom and the negatively charged electron are called an ion pair. Ionization should not be confused with radiation. Ions (or ion pairs) can be the result of radiation exposure and allow the detection of radiation.

Typically, we classify types of radiation as ionizing or non-ionizing radiations depending on whether or not the radiation can form ion pairs in common materials such as air or tissue.

The four basic types of ionizing radiation that are of primary concern to us are alpha particles, beta particles, gamma-rays (x-rays) and neutron particles.

**Non-ionizing radiation** - Radiation that doesn't have the amount of energy needed to ionize an atom. Examples of non-ionizing radiation are ultraviolet rays, microwaves and visible light.

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## Review:

- 1-4. Ionizing radiation may be defined as \_\_\_\_\_ in the form of \_\_\_\_\_ or \_\_\_\_\_ which has sufficient energy to \_\_\_\_\_ matter.
5. Unstable atoms which give off radiation when they decay are known as \_\_\_\_\_ material.
6. Radioactive material on surfaces or in liquids, which might be easily transferred to surfaces or personnel, is known as \_\_\_\_\_
- 7-8. Ionization is the process of removing \_\_\_\_\_ from \_\_\_\_\_.
9. After two half-lives, what percent of the original radioactive material will remain?\_\_\_\_\_.

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## 3.3 Units of Measurement

### 3.3.1 Exposure and Dose

When people are exposed to radiation, the energy of the radiation is deposited in 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 (energy), and in some cases the absorption of the light energy may cause noticeable heating in the body tissue. However, your body does not emit light after it has absorbed it.

In a similar way, when exposed to radiation, your body absorbs the radiation energy. As this absorption takes place, the tissue 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 ensure that 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 equivalent dose) is the rem.

*The rem is the unit used for equating radiation absorption with biological damage.*

Since the rem is a fairly large unit, radiation dose is usually recorded in thousandths of a rem - or millirem (abbreviated mrem).

$$1000 \text{ millirem} = 1 \text{ rem}$$

For example, if you receive a chest x-ray, the amount of exposure - or dose - would be approximately 10 mrem (0.010 rem). This same amount of dose or biological harm, could be received from making two or three coast to coast airline flights - each round trip involves about 5 mrem from elevated cosmic radiation levels in the upper atmosphere.

Other related units are used to make radiation measurements. You will hear several terms such as "exposure", "dose" or "absorbed dose" associated with some of these units. Since these units and terms are used frequently, and have similar meanings they are mentioned here for comparison. The following units are among the most common English units used. The limitations of each of the units are described. These units (the R, the rad, and the rem) are often interchanged, but each has a specific definition.

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The **Roentgen** (pronounced "renken") is a unit for measuring exposure. It is defined only for effect on 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 radiation. Therefore, it is not a measure of energy absorbed, or dose. It applies only to gamma- and x-rays. It does not relate the amount of exposure to biological effects of radiation in the human body.

$$1 \text{ R (Roentgen)} = 1000 \text{ mR (milliRoentgen)}$$

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

$$1 \text{ rad} = 1000 \text{ millirad (mrad)}$$

As stated above, the rem is the unit for measuring the special quantity called equivalent dose. The rem takes into account the energy absorbed (dose) and the relative biological effect on the body due to the type of radiation (expressed as the radiation weighting factor). It 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 exposure is recorded in rem.

$$\text{rem (Roentgen Equivalent Man)} = \text{rad} \times W_R$$

Note: For purposes of this training, the term *dose* will be used to mean equivalent dose.

Dose is the amount of radiation you receive. A dose rate indicates how fast you receive the dose. Dose rate is the intensity of the radiation.

For Example:

- a) Dose - usually measured in mrem
- b) Dose rate - usually measured in mrem/hr

Note: The units R, 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.

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### **Review:**

10. If you stand in an area where the dose rate is 40 mrem/hr for 1/2 hour, what would your dose be? \_\_\_\_\_

11. Exposure to radiation \_\_\_\_\_ (does/does not) result in a person becoming contaminated.

12. The dose rate in a room you are working in is 3 mrem/hr. If you work in this area for a full 8 hour shift, your total dose would be \_\_\_\_\_ mrem.

13. What is the unit for biological damage done by radiation? \_\_\_\_\_

14. a. 200 mrem = 0.2 rem.                          b. 0.1 rem = \_\_\_\_\_ mrem.

c. 1.5 rem = \_\_\_\_\_ mrem.                          d. 10 mrem = \_\_\_\_\_ rem.

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### 3.3.2 Measuring Radioactivity/Contamination

The amount of radioactive material in a given object or sample can be visualized by thinking of the unstable atoms in the material. These atoms are continuously decaying, so the more unstable atoms there are, the greater the decay rate.

This **rate of decay** is measured in units of Curies. Curies are related to the decay rate, or disintegration rate, as follows:

$$1 \text{ Curie} = 2,200,000,000,000 \text{ disintegrations per minute or } 2.2 \times 10^{12} \text{ dpm}$$

Since the Curie is a large number of disintegrations per minute, sub-units of the Curie such as the microCurie or milliCurie are often used. The dpm, on the other hand, is used when measuring surface contamination. For example, when using a frisker to measure contamination, the instrument reading - in counts per minute (cpm) - is converted to dpm by a simple conversion of  $1\text{cpm} \approx 10 \text{ dpm}$  (this assumes a 10% frisker efficiency). Therefore if the frisker reads 100 cpm, the contamination level is 1000 dpm. This is a very small amount of radioactivity.

If your job involves working around contamination, you will receive training on the use of a frisker or other contamination monitoring instruments. Radiation Worker I training does not qualify you to work in Contamination Areas.

#### Review:

15. 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.

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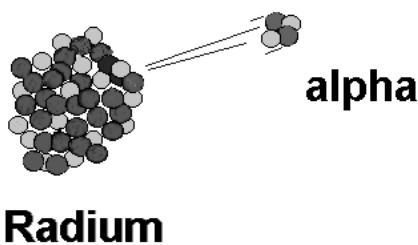
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## 3.4 Types of Ionizing Radiation

The four basic types of ionizing radiation of concern in most radiological work situations are alpha particles, beta particles, gamma-rays and neutron particles. These may exist in various amounts, depending on the exact location and nature of the work. We will examine each type of radiation for its characteristics here, and later in the training look more closely at where we might find each type at TJNAF.

### Alpha particles ( $\alpha$ )

Physical characteristics:



### Radium

Alpha particles are emitted during the decay of certain types of radioactive materials. Compared to other types of particles, the alpha particle has a relatively large mass. It consists of two protons and two neutrons. It is a highly charged particle (+2). The positive charge causes the alpha particle to strip electrons from nearby atoms as it passes through the material, thus ionizing these atoms.

Range:

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

Shielding:

Most alpha particles are stopped by a few centimeters of air, a sheet of paper, or the dead layer of skin (outer layer) on our bodies.

Biological hazard:

Alpha particles are not considered an external radiation hazard. This is because they are easily stopped by the dead layer of skin. If alpha emitting radioactive material is inhaled or ingested, however, it becomes a source of internal exposure. Internally, the source of the alpha radiation is in close contact with body tissue and can deposit large amounts of energy in a small volume of body tissue.

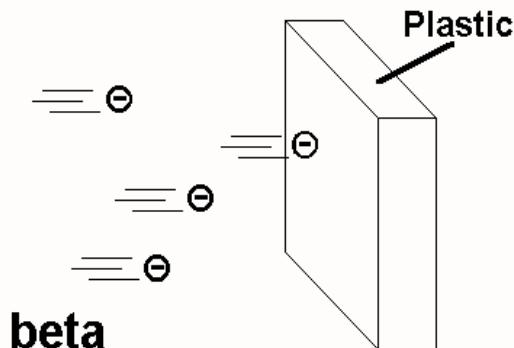
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## Beta particles ( $\beta$ )

Physical characteristics:

The beta particle is an energetic electron or positron emitted during radioactive decay. Compared to an alpha particle, a beta particle is nearly 8000 times less massive and has half the electrical charge. Beta radiation causes ionization by the same forces at work with alpha radiation - mainly electrical interactions with atoms which it encounters as it travels. However, because it is not as highly charged, the beta particle is not as effective at causing ionization. Therefore, it travels further before giving up all its energy and finally coming to rest.



Range:

The beta particle has a limited penetrating ability. Its typical range in air is up to about 10 feet. In human tissue, the same beta particle would travel only a few millimeters.

Shielding:

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 (Bremsstrahlung) in the shield.

Biological hazard:

Externally, beta particles are potentially hazardous to the skin and eyes. They cannot penetrate to deep tissues such as the bone marrow or other internal organs. This type of external exposure leads to what is called a shallow dose. When taken into the body, materials that emit beta radiation can be a hazard in a similar way to that described for alpha emitters - although comparatively less damage is done in the tissue exposed to the beta emitter.

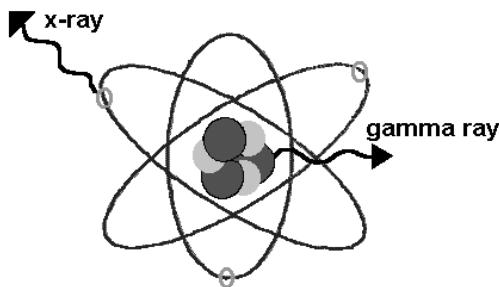
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## Gamma-rays/x-rays ( $\gamma$ )

Physical characteristics:

Gamma/x-ray radiation is an electromagnetic wave or photon. Gamma-rays and x-rays can be thought of as physically identical; the only difference is in their place of origin. These photons have no mass or charge, but they can ionize matter as a result of direct interactions with orbital electrons. Like all electromagnetic radiations, gamma-rays and x-rays travel at the speed of light.



Range:

Because gamma/x-ray radiation has no charge and no mass, it has a very high penetrating power (said another way, the radiation has a low probability of interacting in matter). Gamma-rays have no specific "range", but are characterized by their probability of interacting in a given material. There is no distinct maximum range in matter, but the average range in a given material can be used to compare materials for their shielding ability.

Shielding:

Gamma/x-rays are best shielded by very dense materials, such as lead, concrete, or steel. Shielding is often expressed by thicknesses that provide a certain shielding factor, such as a "half-value layer" (HVL). An HVL is the thickness of a given material required to reduce the dose rate to one half the unshielded dose rate.

Biological hazard:

Due to their high penetrating power, gamma/x-rays can result in radiation exposure to the whole body rather than a small area of tissue near the source. Therefore, photon radiation has the same ability to cause dose to tissue whether the source is inside or outside the body. This is in contrast to alpha radiation which must be received internally to be a hazard. Gamma/x-ray radiation is considered an external hazard. Refer to the definition of "whole body" in the glossary.

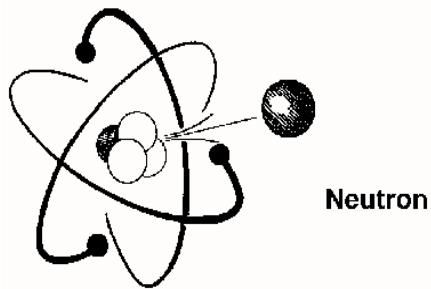
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## Neutron particles (n)

Physical characteristics:

Neutron radiation consists of neutrons that are ejected from the nuclei of atoms. A neutron has no electrical charge. An interaction occurs as the result of a "collision" between a neutron and the nucleus of an atom. A charged particle or other radiation which can cause ionization may be emitted during these interactions. This is called indirect ionization.



Range:

Because neutrons do not experience electrostatic forces, they have a relatively high penetrating ability and are difficult to stop. Like photon radiation, 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.

Shielding:

Moderate to low energy neutron radiation is best shielded by materials with a high hydrogen content, such as water ( $H_2O$ ) or polyethylene plastic ( $CH_2-CH_2-X$ ). High energy neutrons 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.

Biological hazard:

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

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Summary of radiation types and their characteristics.

TYPE	ALPHA	BETA	GAMMA	NEUTRON
PENETRATING POWER	very small	small	very great	very great
HAZARD	internal	internal/external	external	external
SHIELDING MATERIAL	paper	plastic, aluminum	lead, steel, concrete	water, concrete, steel (high energy)
QUALITY FACTOR	20	1	1	2-10

**Review:**

16-19. The four basic types of ionizing radiation are: \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_, and \_\_\_\_\_.

20. Rank the following types of radiation in order of increasing penetrating power:

beta \_\_\_\_\_  
gamma \_\_\_\_\_  
alpha \_\_\_\_\_

21. Classify the following as ionizing radiation or non-ionizing radiation.

Alpha particles \_\_\_\_\_  
Ultraviolet radiation \_\_\_\_\_  
RF (microwave) radiation \_\_\_\_\_  
Neutron radiation \_\_\_\_\_  
Laser radiation \_\_\_\_\_

22. A good shield for beta radiation is \_\_\_\_\_.

23-24. Gamma-rays have no \_\_\_\_\_ or charge, and are, therefore, \_\_\_\_\_ (more/less) likely to interact in a given thickness of material than beta particles.

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## ANSWERS TO UNIT 3 REVIEW QUESTIONS

1. energy
2. particles
3. waves
4. ionize
5. radioactive
6. contamination
7. electrons
8. atoms
9. 25%
10. 20 mrem
11. does not
12. 24
13. rem
14. b. 100 c. 1500 d. 0.01
15. c.
16. alpha
17. beta
18. gamma
19. neutron
20. 1= alpha, 2= beta, 3= gamma
21. a. Ionizing b. Non-ionizing c. Non-ionizing d. Ionizing e. Non-ionizing
22. plastic, aluminum, wood
23. mass
24. less

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## 4 Biological Effects of Radiation

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. In this unit, we will discuss the potential for biological effects and risks due to ionizing radiation and put these potential risks into perspective when compared to other occupations and daily activities.

### 4.1 Effects of Radiation on Cells

The mechanism by which radiation causes damage to human tissue, or any other material, is by ionization of atoms in the 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. This is a basic model for understanding radiation damage.

When ionizing radiation interacts with cells, it may or may not strike a critical part of the cell. We consider the chromosomes to be the most critical part of the cell since they contain the genetic information and instructions required for the cell to perform its function and to make copies of itself for reproduction purposes (DNA).

The following are possible effects of radiation on cells:

#### Cells are undamaged by the dose

Ionization may form chemically active substances which in some cases alter the structure of cells. These alterations may be the same as those changes that occur naturally in the cell and may have no negative effect.

#### Cells are damaged, repair the damage and operate normally

Some ionizing events produce substances not normally found in the cell. These can lead to a breakdown of the cell structure and its components. Cells can repair the damage if it is limited. Even damage to the chromosomes is usually repaired. Many thousands of chromosome aberrations (changes) occur constantly in our bodies. We have effective mechanisms to repair these changes.

#### Cells are damaged, repair the damage and operate abnormally

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. The result may be cells that cannot perform their normal functions or that now are damaging to other cells. These altered cells may be unable to reproduce themselves or may reproduce at an uncontrolled rate. Such cells can be the underlying causes of cancers.

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## Cells die as a result of the damage

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.

All cells are not equally sensitive to radiation damage. In general, cells which divide rapidly and/or are relatively non-specialized tend to show effects at lower doses of radiation than those which are less rapidly dividing and more specialized. Examples of the more sensitive cells are those which produce blood. This system (called the hematopoietic system) is the most sensitive biological indicator of radiation exposure. The relative sensitivity of different human tissues to radiation can be seen by examining the progression of the Acute Radiation Syndrome on the following pages.

## Review:

1. When a cell is damaged by radiation:

- a. it always dies
- b. it may repair the damage and operate normally
- c. it induces radiation poisoning
- d. there is a high probability of cancer

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 may be removed by the immune system
- d. the cell will die

3. The mechanism that causes damage to cells from radiation exposure is\_\_\_\_\_.

4-5. The most radiosensitive cells in the body are those that divide\_\_\_\_\_ , and are relatively (specialized / unspecialized).

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## 4.2 Acute and Chronic Radiation Dose

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

### 4.2.1 Acute Dose

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

Acute doses can cause a pattern of clearly identifiable symptoms (syndromes). These conditions are referred to in general as **Acute Radiation Syndrome**. Radiation sickness symptoms are apparent following acute doses  $\geq 200$  rad. Acute whole body doses of 400-500 rad may result in a statistical expectation that 50% of the population exposed will die within 30 days without medical attention.

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 general health of the individual.

**Hematopoietic (Blood-forming organ / Bone marrow) syndrome** ( $>200$  rad) is characterized by damage to cells that divide at the most rapid pace (such as bone marrow, the spleen, and lymphatic tissue). Symptoms include nausea, vomiting, hair loss (2-3 weeks after exposure). Death can occur 1-2 months after exposure.

**Gastrointestinal tract syndrome** ( $>1000$  rad) is characterized by damage to cells that divide less rapidly (such as the lining of the intestines). Symptoms include nausea, vomiting, diarrhea, dehydration, electrolytic imbalance, loss of digestive ability, bleeding ulcers, and the symptoms of the blood-forming organ syndrome. Death occurs within weeks of exposure.

**Central nervous system syndrome** ( $>2000$  rad) is characterized by damage to cells that do not reproduce, such as nerve cells. Symptoms include loss of coordination, confusion, coma, convulsions, shock, and the symptoms of the blood forming organ and gastrointestinal tract syndromes. Scientists now have evidence that death under these conditions is not caused by radiation damage to the nervous system, but rather from complications caused by internal bleeding, and fluid and pressure build-up on the brain. Death follows within hours to days.

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Effects from an acute doses to localized areas include:

- 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.

As a group, the effects caused by acute doses are called *deterministic*. Broadly speaking, this means that the severity of the effect is determined by the amount of dose received. **Deterministic effects** usually have some threshold level below which the effect will probably not occur, but above which the effect is expected. When the dose is above the threshold, *the severity of the effect increases as the dose increases*.

## 4.2.2 Chronic Dose

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 cells. This is the type of dose received as occupational exposure.

The biological effects of high levels of radiation exposure are fairly well known, but the effects of low levels of radiation are more difficult to determine because the deterministic effects described above do not occur at these levels.

Since deterministic effects do not generally occur with chronic dose, in order to assess the risk of this exposure, we must look to other types of effects. Studies of people who have received high doses have shown a link between radiation dose and some delayed, or *latent* effects. These effects include some forms of cancer and genetic effects.

The risks for these effects are not directly measurable in populations of exposed workers; therefore, the risk values at occupational levels are *estimates* based on risk factors measured at high doses.

To make these estimates, we must use a relationship between the occurrence of cancer at high doses and the potential for cancer at low doses. Since the probability for developing cancer at high doses increases with increasing dose, this relationship is assumed to hold true with low doses. This type of risk model is called **stochastic**.

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Using this model and knowledge of high-dose cancer risks, we can calculate the *probability* of cancer occurrence at a given dose. In this way, the rem can be used as a unit of *potential harm*. For instance, the relatively well known cancer risk from doses in the range of hundreds of rem can be "scaled down" to assess the potential risk from a dose of 100 mrem (0.1 rem). This scaling, or extrapolation, is generally considered to be a conservative approach to estimating low-dose risks (may over-estimate the risk).

We will use such estimates in a moment to help put the risks from exposure into perspective.

The table below places the possible effects from acute and chronic dose into risk categories. We will look at a comparison of the amount of risk involved in a moment.

	Risk for deterministic effects?	Risk for stochastic effects?
Can acute dose cause -	Yes - Thresholds appear at various levels for different effects. Classified as "early" somatic effects.	Yes - Probability of occurrence varies in $\approx$ linear manner with dose. Classified as "latent" effects.
Can chronic dose cause -	Some - A few deterministic effects can occur with long term exposure <u>IF</u> dose exceeds the threshold for the effect. Example- cataracts. (Dose limits are set such that these thresholds are not expected to be reached in a normal working lifetime).	"Assumed" Yes - Probability for occurrence is extrapolated from dose-effect curve for high doses. At occupational levels, epidemiological data cannot confirm or refute the calculated magnitude of risk.

## 4.3 Somatic vs. Genetic Effects

**Somatic effects** appear in the exposed person. Somatic effects may be divided into two classes based on the rate at which the dose was received.

**1. Prompt somatic effects** are those that occur soon after an acute dose (typically 10 rad or greater to the whole body). One example of a prompt effect is the temporary hair loss which occurs about three weeks after a dose of 400 rad to the scalp. New hair is expected to grow within two months after the dose, although the color and texture may be different.

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2. **Delayed somatic effects** are those that may occur years after radiation doses are received. Among the delayed effects thus far observed have been an increased potential for the development of cancer and cataracts. Since some forms of cancer are among the most probable delayed effects, the established dose limits were formulated with this risk in mind. These limits are set such that the calculated risk of cancer in radiation workers is an increase of a very small fraction above the normal cancer risk.

**Genetic, or heritable effects** are abnormalities that may occur in the future generations of exposed individuals. They have been extensively studied in plants and animals, but genetic effects have never been seen in humans. Therefore, the limits used to protect the exposed person from harm are equally effective in protecting future generations from harm.

## 4.4 Prenatal Radiation Exposure

An embryo/fetus is especially sensitive to radiation (rapidly dividing cells), particularly in the first 20 weeks of pregnancy.

This radiation exposure may be the result of exposure to external sources of radiation or internal sources of radioactive material.

Potential effects associated with prenatal radiation doses include:

- Growth retardation
- Small head/brain size
- Mental retardation
- Childhood cancer

At occupational dose limits, however, the actual probability of any of these effects occurring from exposure of the mother is small.

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## **Review:**

6. A large dose of radiation in a short period of time is called a(n) \_\_\_\_\_ dose.
7. If a person receives a rapid dose of 10 rads, what prompt effects are expected to be seen?  
\_\_\_\_\_.
8. A relatively small dose over a long period (i.e. 2 rem/yr for 25 years), is known as \_\_\_\_\_ dose.
9. Prenatal exposure refers to radiation dose received:
  - a. during childhood
  - b. by an embryo/fetus during pregnancy
  - c. by an adult female prior to her becoming pregnant

## **4.5 Comparison of Risks**

Acceptance of a risk is a highly personal matter. It requires a good deal of informed judgment. The risks associated with occupational radiation doses are considered acceptable as compared to other occupational risks by virtually all the scientific groups who have studied them. The following chart may help you put the potential risk of radiation into perspective when compared to other occupations and daily activities.

*Did you know?* If you don't smoke, your overall risk for death from cancer - not counting occupational radiation exposure - is about 20%.

Estimated days of life expectancy lost from various risk factors.

<b>Industry Type or Activity</b>	<b>Estimated Days of Life Expectancy Lost</b>
Smoking 20 cigarettes a day	2370 (6.5 years)
Overweight by 20%	985 (2.7 years)
Mining and Quarrying	328
Construction	302
Agriculture	277
Government	55
Manufacturing	43
Radiation - 340 mrem/yr for 30 years	49
Radiation - 100 mrem/yr for 70 years	34

Note: The "life expectancy lost" value is determined from data on percentage of deaths due to the risk factor weighted by the average age at death. Since radiation related deaths are calculated values, they are based on the assumption of cancer as the cause of death, with the associated average age of death from cancer victims. All radiation risk values are based on the report from the National Academy of Sciences' *Biological Effects of Ionizing Radiation* (BEIR) series - BEIR V.

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**A Comparison:** Remember the 20% cancer risk mentioned earlier? If you receive 400 mrem/yr for 30 years, your calculated cancer risk is 20.5%. Smokers have a 25% cancer risk.

The table below presents another way of looking at health risks. This table lists activities calculated to have a 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)

## Conclusions Regarding Health Risks

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 later. Minimizing the dose minimizes the risk.

## Review:

10. If a person received a dose of 1 rem/yr for 50 years, what effects are expected to be seen?  
\_\_\_\_\_.
11. A radiation dose of 5 rem/yr for 50 years is thought to involve \_\_\_\_\_ (more/less) risk than cigarette smoking. (Hint: this dose is about 20 times higher than the example of 340 rem/year for 30 years.)
12. A burn to the skin is an example of a \_\_\_\_\_ effect.
13. Induction of cancer due to radiation exposure is an example of a \_\_\_\_\_ effect.
14. The risks of heritable genetic effects occurring from radiation are estimated to be \_\_\_\_\_ (greater/smaller) than the risks for cancer induction.
15. The risk to a developing embryo/fetus from radiation exposure is greater than for an adult because its cells are \_\_\_\_\_ and rapidly dividing.

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## 5 Sources of Radiation

We live in a radioactive world. There are many natural sources of radiation which have been present since the earth was formed. In the last century, we have added somewhat to this natural background radiation with some artificial sources.

### 5.1 Natural Radiation

The three major sources of **naturally occurring radiation** are:

- cosmic radiation (galactic and solar)
- sources in the earth's crust, also referred to as terrestrial radiation
- sources in the human body, also referred to as internal sources.

**Cosmic radiation** comes from the sun and outer space and consists of charged particles, as well as gamma radiation. At sea level, the average cosmic radiation dose is about 26 mrem per year. At higher elevations the amount of atmosphere shielding cosmic rays decreases and thus the dose increases.

There are natural sources of radiation in the ground, rocks, building materials and drinking water supplies. This is called **terrestrial radiation**. Some of the contributors to terrestrial sources are natural radium, uranium, and thorium. Radon gas is a health concern. This gas is produced by the decay of natural uranium in soil. Radon, which emits alpha radiation, rises from the soil under houses and can build up in homes, particularly well-insulated homes. In the USA, the average effective whole body dose from radon is about 200 mrem per year.

Our bodies also contain natural radionuclides. Potassium-40 is one example. The total average dose from internal sources is approximately 40 mrem/year.

### 5.2 Human Sources

The difference between man-made sources of radiation and naturally occurring sources is the place from which the radiation originates. The following information briefly describes some examples of human-made radiation sources.

#### Medical radiation sources

X-rays are identical to gamma-rays; however, they are produced by a different mechanism. A typical radiation dose from a chest x-ray is about 10 mrem. In addition to x-rays, radionuclides are used in medicine for diagnosis and therapy. Because of the large increase in the use of medical imaging procedures such as computed tomography (CT) and nuclear medicine, medical sources of radiation now contribute about 36% of the average total radiation exposure of individuals in the United States.

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## Consumer products

Examples of consumer products include TV's, older luminous dial watches, some smoke detectors, and lantern mantles. This dose is relatively small compared to naturally occurring sources of radiation and averages 10 mrem in a year.

## Atmospheric testing of nuclear weapons

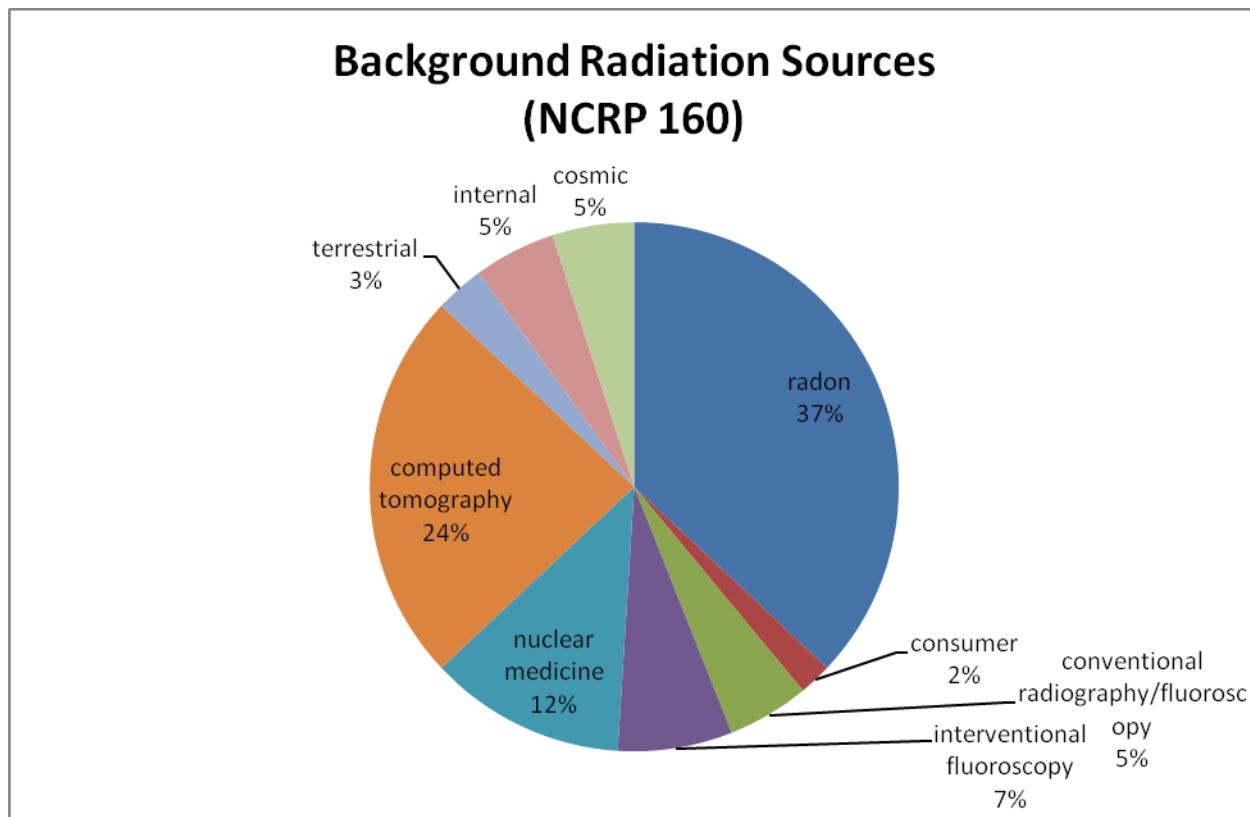
Another man-made source of radiation is residual fallout from atmospheric nuclear weapons testing in the 1950's and early 1960's. Atmospheric testing is now banned by most nations. The average dose from residual fallout is about 1 mrem in a year.

## Industrial uses

Industrial uses of radiation include x-ray machines and radioactive sources (radiography) used to test pipe welds, bore-holes, etc. Most people receive little if any dose from these sources.

As a whole, these sources of natural and human-made radiation are referred to as **background**.

The average annual radiation dose to a member of the general population in the US from *all* background sources is about 620 millirem.



We will discuss specific sources of radiation at TJNAF later in the course.

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## **Review:**

16. The average American receives about \_\_\_\_\_ mrem/yr from all sources of background radiation.
17. The largest part of our background exposure comes from.
  - a. diagnostic x-rays
  - b. naturally occurring sources of radiation and radioactivity in the environment
  - c. nuclear weapons fallout
  - d. industrial radiography

## **ANSWERS TO UNIT 4 and 5 REVIEW QUESTIONS**

1. b.
2. c.
3. ionization
4. rapidly
5. unspecialized
6. acute
7. none
8. chronic
9. b.
10. none
11. less
12. prompt somatic
13. delayed somatic
14. less
15. unspecialized
16. 620
17. b.

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## 6 Radiation Exposure Minimization - ALARA

In order to minimize the potential risks of biological effects associated with radiation, dose limits have been established. Even though there are dose limits and administrative control levels, we strive to keep our radiation dose well below these through the ALARA concept.

### 6.1 ALARA Concept

ALARA stands for As Low As Reasonably Achievable.

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 here at TJNAF. This concept includes reducing both internal and external exposure to ionizing radiation.

#### What is "reasonable"?

The ALARA concept itself grows out of our assumption that any radiation exposure carries with it some risk. Since work that entails radiation exposure is sometimes part of some beneficial endeavor, the ALARA effort is related to balancing the assumed risks of radiation exposure against the benefit of performing the work. So "reasonable" in this context means that the risk from receiving the exposure is "worth" the net benefit of the activity. An extension of this philosophy would be the statement 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."*

In other words, ALARA means preventing unnecessary exposure as well as overexposure.

The implementation of the ALARA concept is the responsibility of all employees. The success of the ALARA program depends on each radiological worker's attitude and actions. The ALARA concept should be a routine element of your work in radiological areas.

#### Review:

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 ALARA.
2. ALARA stands for \_\_\_\_\_.
3. What factors are considered when deciding whether a dose of radiation is "reasonably low"?

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## 6.2 Responsibilities for the ALARA Program

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

### Management

TJNAF management's responsibilities include:

1. Implementing policies and procedures to maintain radiation exposures ALARA.
2. Establishing radiation exposure goals and guidelines.
3. Communicating radiological goals to all personnel through line management.
4. Tracking and evaluating radiological performance.
5. Providing a feedback mechanism for reporting performance and implementing improvements and corrective actions.

### Radiological Control Personnel

The Radiation Control Department is responsible for:

1. Implementing radiological requirements, limits, guidelines, and procedures.
2. Monitoring radiological work in progress to ensure radiologically safe practices are used.
3. Measuring, documenting, and tracking personnel exposures and the environmental impact of radiological work.
4. Evaluating radiological performance and advising TJNAF management in implementing improvements.

### Radiation Workers

Each radiological worker is responsible for:

1. Knowing and minimizing his/her exposure.
2. Complying with all radiological rules and written/oral instructions from RCD personnel.
3. Being familiar with emergency procedures.
4. Being alert for and responding to unusual radiological situations.
5. Knowing where/how to contact the RCD.

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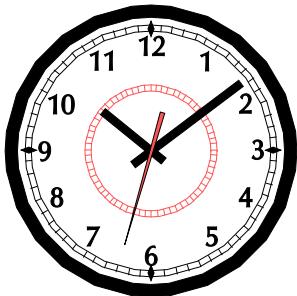
## 6.3 Dose Reduction Practices

The main goal of the ALARA program is to reduce both the external and internal radiation doses to a level that is As Low As Reasonably Achievable.

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

1. minimizing time in a field of radiation
2. maximizing the distance from a source of radiation
3. using shielding whenever possible

Methods for minimizing time:



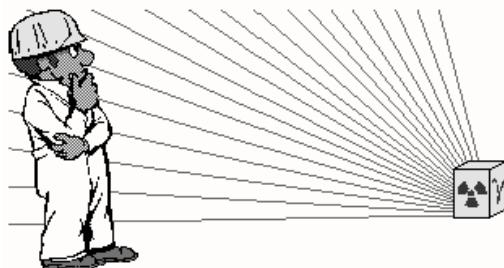
Pre-plan and discuss the task thoroughly prior to entering the area. Use only the number of workers actually required to do the job.

- Have all necessary tools before entering the area.
- Use mock ups and practice runs.
- Take the most direct route to the job site.
- Never loiter in an area controlled for radiological purposes.
- Work efficiently but swiftly.
- Do the job right the first time.
- Perform as much work outside the area as possible.

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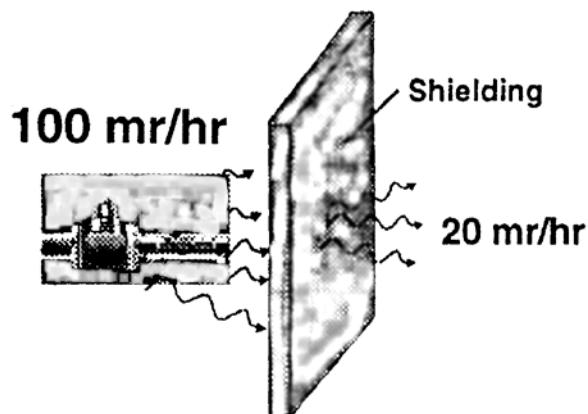
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## Methods for maintaining distance from sources of radiation:



- Stay as far away as possible from the source of radiation.
- For point sources, the dose rate follows the inverse square law. If you double the distance, the dose rate falls to 1/4. If you triple the distance, the dose rate falls to 1/9.
- Be familiar with radiological conditions in the area. During work delays, move to lower dose rate areas.
- Use remote handling devices when possible.

## Proper uses of shielding:



- Shielding reduces the amount of radiation dose to the worker. Different materials shield a worker from the different types of radiation.
- Use permanent shielding such as non-radiological equipment/structures.
- Use shielded containment (e.g., glove boxes, etc.) when available.
- Wear safety glasses/goggles to protect the eyes from beta radiation, when applicable.
- The placement of shielding may actually increase total dose (e.g., man-hours involved in placement, Bremsstrahlung, etc.).
- Temporary shielding (e.g. lead or concrete blocks) can only be installed when procedures are used. Once temporary shielding is installed, it cannot be removed without proper authorization.

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## Additional methods to reduce dose:

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

## Review:

4. Who should establish radiological goals and policies, and communicate these to TJNAF personnel?

- a. The Radiation Control Department
- b. The first line supervisor
- c. The DOE
- d. TJNAF management

5. Who is responsible for keeping your dose ALARA ? \_\_\_\_\_

6-8. To implement ALARA, the basic controlling principles are \_\_\_\_\_, \_\_\_\_\_, and \_\_\_\_\_.

9. You can help minimize radioactive waste production by:

\_\_\_\_\_.

## ANSWERS TO UNIT 6 REVIEW QUESTIONS

1. minimize
2. As Low As Reasonably Achievable
3. In short, the relative benefit of the activity. Specific considerations may include any or all of the following: Cost, lost time, potential corresponding exposure to other risks when reducing radiation exposure, potential increased radiation exposure that may occur during the exposure reduction effort (i.e. dose accrued when installing shielding), public perception, etc.
4. d.
5. You
6. time
7. distance
8. shielding
9. Cleaning up debris, tools and materials which have been used during work in the beam enclosure, thereby preventing them from becoming radioactive during operations

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## 7 Dose Limits

### 7.1 DOE Dose Limits and Facility Administrative Control Levels

The facility administrative control levels for radiological workers are more conservative than the DOE dose limits and are established to ensure the DOE limits are not exceeded and to support the ALARA concept.

The DOE dose limits and TJNAF administrative control levels are as follows:

DOE whole body dose limit for routine exposures = 5 rem/year

TJNAF's administrative control level for whole body = 1 rem/year

The **whole body** extends from the top of the head down to just below the elbows and just below the knees. This is the location of most of the blood-producing and vital organs. Since the whole body contains the most radiation-sensitive organs, it has the lowest limit.

Limits are based on the sum of internal and external exposures. When individual organs are exposed, the following limits apply (the whole body dose limit must still be met).

Summary of organ dose limits and TJNAF control levels.

ORGAN	DOE DOSE LIMIT	TJNAF CONTROL LEVEL
Extremities	50 rem/year	10 rem/year
Skin and other organs	50 rem/year	10 rem/year
Lens of the eye	15 rem/year	3 rem/year

### 7.2 Declared Pregnant Workers

DOE policy states that a female radiological worker should be encouraged to voluntarily notify her supervisor, in writing, when she is pregnant. 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.

For a declared pregnant worker who continues working in radiological areas, the following radiation dose limits will apply:

- The dose limit for the embryo/fetus is 500 mrem (during entire gestation period).
- Efforts should be made to avoid exceeding 50 millirem/month to the pregnant worker.

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If the dose to the embryo/fetus is determined to have already exceeded 500 mrem when a worker notifies her employer of her pregnancy, the worker should not be assigned to tasks where additional occupational radiation exposure is likely during the remainder of the pregnancy.

It is important to note that the declaration of pregnancy is a voluntary measure taken by the expectant mother. No special dose limitations may be applied to pregnant workers without their written consent in the form of the declaration of pregnancy. If you have any questions regarding this policy, you should contact the RCD.

## 7.3 Non-Radiation Workers

The radiation dose limit for visitors and the public is 100 mrem/year.

### Review:

1. The DOE has established a dose limit for the whole body of \_\_\_\_\_ rem/yr for radiation workers.

2. The extremity dose limit is \_\_\_\_\_ (higher/lower) than the whole body dose limit.

3. Why are the dose limits for the skin, extremities, and other organs higher than the whole body dose limit?  
\_\_\_\_\_  
\_\_\_\_\_

4. The dose limit for a declared pregnant worker is \_\_\_\_\_ mrem for the duration of the pregnancy.

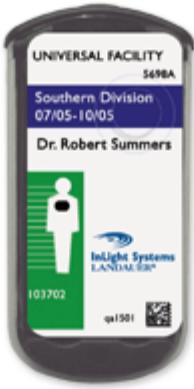
5. If a worker is "declared pregnant" it means that she has:

- a. told the medical department about it
- b. been removed from all radiation exposure
- c. notified her supervisor in writing of the pregnancy
- d. been identified as being pregnant by the medical department

6. If a pregnant worker does not "declare" pregnancy, her dose limit is \_\_\_\_\_.

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## 8 Personnel Radiation Monitoring



*Personnel dosimeter (OSL)*



*ring dosimeter*



*SRPD*

### 8.1 External Dosimetry

Dosimeters are radiation detection devices used to record the dose received by the wearer. The two types of dosimeters routinely used at TJNAF are the optically stimulated luminescent (OSL) personnel dosimeter and the Self Reading Pocket Dosimeter (SRPD).

#### 8.1.1 Personnel Dosimeter

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

#### 8.1.2 Self Reading Pocket Dosimeters

The term Self Reading Pocket Dosimeter applies to any of a variety of devices which can be read by the wearer to determine the dose received. The SRPD is usually used as a supplemental device to aid in dose tracking during activities where elevated doses are possible.

Electronic SRPDs are used when it is helpful to have the additional capability of dose or dose rate alarm functions. The electronic dosimeter has a broad dose range and is usually very accurate.

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## 8.2 Proper Use of Dosimetry

- Wear dosimetry at all times in Radiologically Controlled Areas and when required by signs, work permits or the RCD.
- Dosimetry must be worn on the chest between the waist and the neck or as defined in radiological procedures, RWPs, or as directed by the RCD.
- When supplemental dosimeters are required, wear them in close proximity (within 3 inches) to the primary dosimeter.
- In the case of an irregular reading on a supplemental dosimeter (alarm in the case of an electronic dosimeter):
  - Secure work activities
  - Alert others working in the area
  - Immediately exit the area
  - Notify RCD personnel
- Report lost, damaged or potentially compromised dosimeters immediately (e.g. the dosimeter was inadvertently taken offsite and exposed to x-rays from a medical exposure).

### Dosimeter Issuance

OSLs and supplemental dosimetry are issued from the RCD office. If you are escorting a visitor into a Radiologically Controlled Area, you must bring the visitor to the field office for issuance of a temporary dosimeter (usually an SRPD). All supplemental and visitor dosimetry must be returned to the RCD at the end of the work shift. *Do not take visitors into Radiation, High Radiation, Contamination, or Airborne Radioactivity Areas!*

## 8.3 Internal Monitoring

Internal uptake of radioactive material (internal contamination) can cause additional dose to the whole body or individual organs. Radioactive material can enter the body in one of the following ways:

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

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## Internal Monitoring Methods

To indirectly measure the amount of radioactive material present inside the body, whether from naturally occurring or inadvertent uptakes, whole body counters (in-vivo) and/or bioassay samples (in-vitro) may be used. From this measurement, an internal dose may be calculated.

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 from operations at TJNAF are extremely unlikely, and do not require routine monitoring of workers. However, periodic representative sampling may be performed to verify the effectiveness of our radiological control program.

## **8.4 Access to Dose Records**

Your radiation exposure records are maintained by the Radiation Control Department. You have the right to inspect your dose records at any time. If you have questions about your dose or want to review your records, you may request to see your dose record file. If you would like a written dose history report, make a request at the RCD office. You will receive a written report of your dose history annually, and if requested, upon termination of your employment or assignment at TJNAF.

## **8.5 Your Responsibilities Regarding Dose Records**

Prior to initial dosimeter assignment, you must provide a written list to the RCD of prior employment involving radiation exposure. Once your dose history at TJNAF begins, you have several important responsibilities regarding your dosimetry and dose records.

- Notify RCD personnel prior to and following any radiation dose received at another facility so that dosimetry records can be updated. If you are a radiation worker at another facility, you must inform the RCD when you apply for a dosimeter
- Do not take your TJNAF dosimetry to any other facility where you may receive radiation exposure.
- Notify the RCD of any medical administration of radioactive material (this does not include routine medical and dental x-rays). Do not wear your dosimetry or enter any Radiologically Controlled Areas following such treatment until approved by the RCD.
- Notify the RCD when your work assignment at TJNAF has ended.
- Know the proper dosimetry storage location. Never take your dosimetry home or offsite. Dosimetry must be returned for processing periodically. Personnel who fail to return dosimetry will be restricted from continued radiological work.

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## **Review:**

7. Your TLD badge is sensitive to \_\_\_\_\_ (which types) radiation.
8. Proper use of the OSL dosimeter includes storing it in \_\_\_\_\_ when not in use.
9. In addition to the personnel dosimeter, supplemental dosimetry such as the \_\_\_\_\_ may be used when elevated dose rates are present.
10. The main reason for wearing a supplemental dosimeter is to allow you to:
  - a. receive radiation dose above the administrative control level
  - b. work in highly contaminated areas
  - c. work in the beam enclosure when beam is present
  - d. closely track your radiation dose when working in significantly elevated radiation levels
11. If you damage, lose, or suspect your dosimetry is operating abnormally, you should \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_ and \_\_\_\_\_.
12. Your dosimeter is designed to:
  - a. measure your external radiation exposure
  - b. measure your internal radiation exposure
  - c. protect you from excessive radiation exposure
  - d. all of the above
13. TJNAF's dosimetry program does not include routine internal monitoring because \_\_\_\_\_.
14. If you receive dose at another facility while employed at TJNAF you must:
  - a. have your TJNAF dosimeter read immediately
  - b. take your TJNAF dosimeter to the other facility
  - c. notify the RCD upon returning to TJNAF
  - d. be restricted from radiological work at TJNAF until your dose records arrive from the other facility
15. Any medical administration of radioactive material should be reported to the RCD so that they can:
  - a. calculate your dose from the administration
  - b. make sure that you are medically able to continue work
  - c. ensure that the medical exposure is not recorded on your TJNAF dosimeter
  - d. evaluate whether the administration is within the legal guidelines

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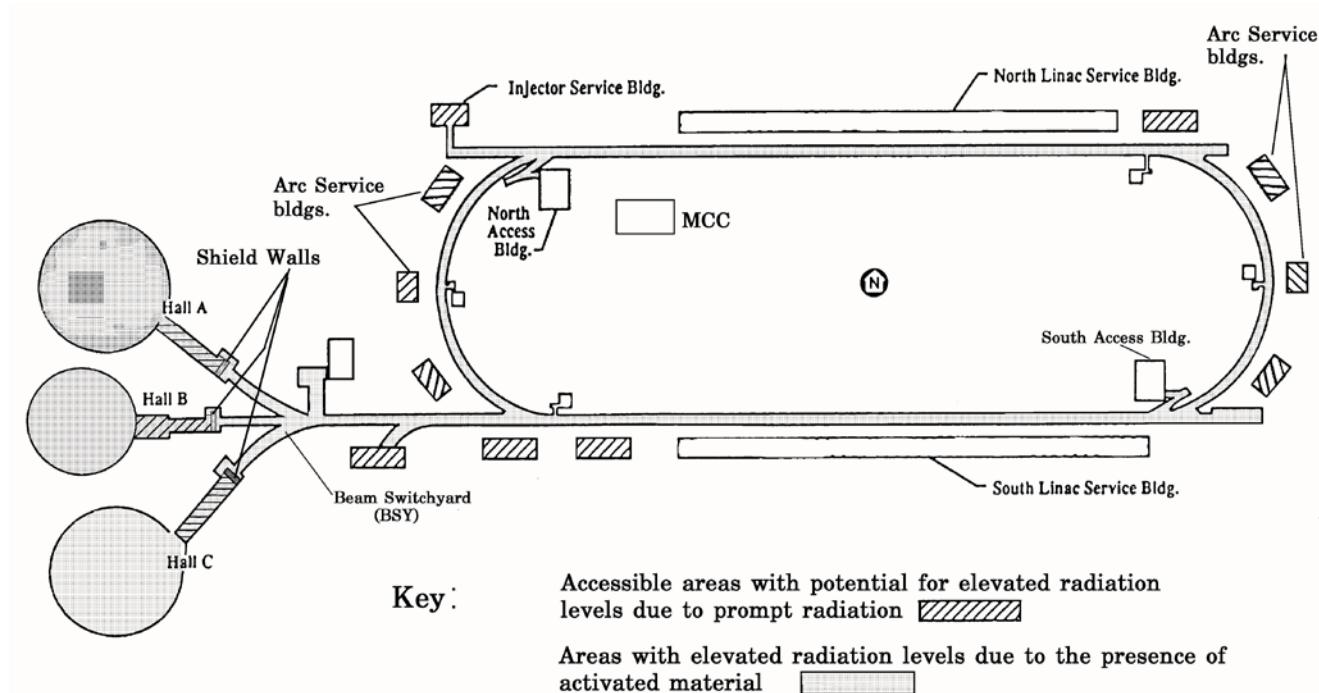
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## ANSWERS TO UNIT 7&8 STUDY QUESTIONS

1. 5
2. higher
3. A given dose to these organs, when irradiated individually (such as skin dose arising from beta exposure) does not result in as much risk for long term effects when compared with a whole body dose.
4. 500
5. c.
6. 5 rem/year
7. beta, gamma, neutron
8. the assigned badge rack
9. Self Reading Pocket Dosimeter
10. d.
11. stop work, alert others in the area, exit immediately, notify the RCD
12. a.
13. the potential for any significant internal deposition of radioactivity is extremely small at TJNAF
14. c.
15. c.

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## 9 Sources of Radiation at TJNAF



### 9.1 Accelerator Produced Radiation and Radioactive Material

The high energy nature of TJNAF's electron beam has the potential to produce high levels of radiation when the beam is on as well as the ability to produce radioactive material in the systems and surrounding structure of the beam enclosure.

#### 9.1.1 Prompt 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. Prompt radiation consists mainly of high energy photons and neutron radiation.

Prompt radiation within the beam enclosure is the most intense radiation present at TJNAF. Direct exposure to a particle beam or secondary radiation "shower" could result in a potentially dangerous or lethal dose of radiation. (Dose rates in the enclosure may exceed  $10^6$  rad/hr). Interlocked access points

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provide a fail-safe barrier against direct beam exposure during operation. Additionally, the accelerator tunnel is well shielded by its underground design. There are a few locations where radiation levels can be elevated due to the proximity of the beam enclosure. These include:

- Above unshielded penetrations in the accelerator service buildings
- Roof of operating end stations
- Accessible shielded labyrinths in the vicinity of the beam enclosure

Always consult the Radiation Control Department, operational safety procedures, or the operations Crew Chief for requirements for working in these areas.

## **9.1.2 Residual Radioactivity**

In addition to prompt radiation, the interaction of TJNAF's high energy beam with matter can cause the formation of radioactive materials. This process is often referred to as "activation", and the radiation itself as "residual radiation". Activated materials emit mostly gamma and beta radiation. This radioactive material emits radiation for some time following operation of the beam. Many of these materials are short-lived and become stable within days or weeks of activation. Others require years to decay to stable nuclides. Exposure to activated materials is a major contributor to worker dose at accelerators such as TJNAF.

It is important to remember that activation can occur in any material subjected to TJNAF's activating primary radiation field. Important sources of activation include:

- Beam dumps and stops
- Magnets
- Beam-lines and beam-line components
- Targets
- Detectors
- Other experimental equipment

Other materials which may become activated are lubricants, cooling water, and air that is contained in spaces within the beam enclosure. 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.

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## 9.1.3 Survey Requirements

Because of the potential for elevated dose rates in the beam enclosure, a radiation survey must be performed upon each entry following beam operations. The purpose of this survey is to identify significant activation or contamination sources so that appropriate radiological controls can be established. Such surveys are normally conducted by RCD personnel.

- Any tools, equipment, components, or structural material present in the beam enclosure are subject to becoming radioactive and must be monitored prior to removal from the enclosure.
- Only RCD personnel may approve the release of such material.

## 9.1.4 Activation and Contamination

It is important to understand the difference between "activated material" and "contaminated material". Contaminated materials are items which either have removable surface contamination or contamination which is fixed in the surface but may be removed by abrasion or chemicals. Radioactive liquids are also a source of contamination. Activated materials are thought of as items which are "contaminated in depth or volume" 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. However, activated materials can become a source of contamination during activities such as:

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

ANY such modification to radioactive material, including beamline components and the structural components of the enclosure, requires RCD concurrence.

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Contamination can also occur due to the activation of materials which are inherently transferable, such as dust, rust, lubricants, and liquids. Items and systems which may be sources of contamination include:

- beam dump and component cooling water (LCW), and filters or ion exchange media
- surface coatings (dust, rust, epoxy, etc.) on beamline components
- vacuum pump oil used in the beam enclosure
- tunnel and end station air handling and dehumidification equipment
- any item which has been directly irradiated by the beam, such as an experimental target

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

Spills or accidental damage to radioactive sources may cause personnel contamination. The proper response to accidents or incidents of this type is covered in a later section of this guide.

## 9.2 Non-Accelerator Sources

There are other sources of radiation at TJNAF 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. You must be specifically approved to use these sources by the Radiation Control Department and the appropriate source custodian.
- The radio-frequency (RF) cavities used to accelerate TJNAF's beam produce x-rays when operated; therefore, they may only be operated in shielded, interlocked enclosures. These cavities are tested in shielded enclosures in the Test Lab.
- Some equipment such as klystron tubes, high voltage power supplies, and other high energy electrical equipment may also produce x-rays when operated.

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## **Review:**

1. Two broad categories of radiation sources at accelerators are known as \_\_\_\_\_ and \_\_\_\_\_.
2. Prompt radiation from the electron beam includes \_\_\_\_\_ and \_\_\_\_\_ radiation.
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 TJNAF
4. You can be exposed to prompt radiation when:
  - a. working in the accelerator tunnel after beam shutoff
  - b. handling sealed radioactive sources
  - c. working in a linac service building during beam operation
5. Radioactive contamination may be found:
  - a. in fines, 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 \_\_\_\_\_ (does/does not) require contamination control measures.
7. Use of sealed radioactive sources requires authorization by the RCD and permission from the \_\_\_\_\_.
8. The main reason for performing a radiation survey after beam operations is:
  - a. to ensure that the beam does not come on while personnel are in the enclosure.
  - b. to determine the levels of residual radioactivity and establish controls based on the levels.
  - c. because high levels of airborne radioactivity may exist.

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9. To remove an item from the beam enclosure which was present there during beam operations:

- a. it must be tested for tritium by the industrial hygiene department.
- b. it must be surveyed by an RCD member or ARM.
- c. no special precautions are required, as long as it was not part of the beam line.
- d. you must frisk it with a contamination monitor.

### ANSWERS TO UNIT 9 STUDY QUESTIONS

1. Prompt, Residual (Activation)
2. gamma, neutron
3. d.
4. c.
5. d.
6. does not
7. the source custodian
8. b.
9. b.

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## 10 Radiation Controls in the Workplace

### 10.1 Radiation Control Department Responsibilities

The Radiation Control Department implements the requirements for the radiological control program. These requirements are established in DOE Orders and regulations, TJNAF's Radiological Control Manual, and site radiological control procedures.

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

### 10.2 Assigned Radiation Monitors

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

- Performing general surveys of the beam enclosure after beam operations
- Surveying and assisting with disposition of equipment removed from the beam enclosure
- Initial response to alarming radiation monitoring equipment or abnormal events

### 10.3 Types of Radiological Controls

Radiological controls can be grouped into two broad categories - engineered controls and administrative controls. Sometimes the two methodologies overlap in their implementation. Consider how the basic ALARA principles of time, distance, and shielding are implemented through each of these types of controls.

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## **10.3.1 Engineered Controls**

Engineered controls consist of equipment designed to protect personnel from a hazard by preventing access to enclosures, providing a warning of the hazard or a means to remove the hazard. These controls may be active or passive.

Examples of engineered controls used at TJNAF include:

### Passive Engineered Controls

Installed shielding  
Walls, gates, or locked doors  
Labyrinths  
displays

### Active Engineered Controls

Key controls  
Interlocked monitoring instruments  
Warning indicators or status  
Ventilation systems

TJNAF's design incorporates heavy use of shielding. The earth overburden on the beam enclosure is an obvious example. Structures such as earth berms, and concrete walls are considered permanent shielding.

Temporary shielding (e.g. lead or concrete blocks) cannot be removed or altered without proper authorization. Temporary shielding will be marked or labeled with wording such as, "Temporary Shielding - Do Not Remove Without Permission from RadCon". This is an example of the combination of an engineered control (the shielding) and an administrative control (the labeling and tracking of these structures).

## **10.3.2 Administrative Controls**

### **10.3.2.1 Configuration Controls**

The above example of labeled shielding is known as a configuration control. Elements of the configuration control program include:

- Labeling and inventory of controlled devices
- Periodic inspections
- Procedures for change and/or restoration of configuration
- Testing to verify proper configuration

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Other examples of structures and equipment to be maintained in a specific configuration are:

- Critical safety devices (certain beam monitors, beam stops, or magnets)
- Safety interlocks and "crash" switches
- Controlled Area Radiation Monitors and their detectors
- Wiring, interconnects, computers and controllers for the above

## **10.3.2.2 Radiological Postings**

Postings (signs, tags, labels) are used to alert personnel of an existing or potential radiological hazard and to aid them in minimizing exposures and preventing the spread of contamination. Radiological postings are the primary means of communicating radiological hazards to workers. All personnel are required to comply with these postings. Disregard for postings or other radiological instructions is grounds for disciplinary action.

### CONTROLLED AREA

An area to which access is controlled in order to protect individuals from exposure to radiation and radioactive materials is known as a Controlled Area. It is a boundary area around other radiological areas and radioactive material storage areas. The TJNAF accelerator site (fenced in area bounded by locked or guarded access gates) has been designated as a Controlled Area. This means that within this area, you are likely to see postings for radiological areas, or radioactive material or possibly encounter slightly elevated levels of radiation. By design, a person who spends their entire work year only in the Controlled Area is not expected to receive enough radiation dose to require dosimetry.

Requirements for entering Controlled Areas:

- training in radiological controls (GERT, Radiation Worker I, or ARM training) -or-
- an escort who is trained at least to the GERT level

The security guard at the accelerator site access will check your identification badge to ensure you have had the appropriate training.

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You may also find Controlled Areas in:

- Locations within the Test Lab (Bldg 58)
- Locations within the EEL Building (Bldg 90)
- Designated Radioactive Material Storage Areas around the site

## RADIOLOGICALLY CONTROLLED AREAS

Areas within the Controlled Area boundary are clearly posted to alert personnel to the presence of elevated radiation levels and/or radioactive materials. In these areas, radiation levels are high enough that personnel may receive more than 100 mrem in a year. Radiologically Controlled Areas contain radiation levels that require personnel radiation monitoring (dosimetry) for entry.

Requirements for unescorted entry:

- dosimeter
- Radiation Worker I training
- Signature on General Access RWP

All Radiologically Controlled Areas are identified by the following:

- Signs that have the standard radiation symbol colored magenta (purple) 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.
- All Radiologically Controlled Area postings will contain the words "Radiologically Controlled Area", or "RCA".
- Personnel dosimetry requirements will also be included on the posting.

Requirements for working in a Radiologically Controlled Area include:

- Practice ALARA - minimize your time in the area
- Do not eat, drink, or smoke in the RCA
- Minimize waste production, and segregate waste according to posted instructions
- Maintain visual and verbal communications with any escorted visitor
- Obey all posted radiological instructions

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Typical Locations of Radiologically Controlled Areas at TJNAF:

- Linac/Arc service buildings
- Beam enclosures (including experimental halls)
- Operating end station roof
- Areas within the EEL and Test Lab

When leaving a Radiologically Controlled Area:

- Make sure you have not left unnecessary waste items in the area
- Check to make sure you have your dosimetry (read your SRPD, if applicable)
- Check for personnel contamination monitoring requirements - some areas may require a contamination check prior to leaving. If monitoring is required, follow the procedures discussed later in the handout.

Within a Radiologically Controlled Area, various other radiological postings may exist. These areas are usually defined by specific levels of radiation or contamination which may exist within. The definitions and requirements for working in these areas follow.

## RADIATION AREA

Areas where the whole body radiation dose rates (30 cm. from the source of radiation) are >5 mrem/hr but <100 mrem/hr. The postings/signs will include the words "CAUTION RADIATION AREA".

- All of the precautions for working in an RCA apply. Check the posting to determine if an RWP is necessary. Notify the RCD when performing activities which might change radiological conditions, such as moving radioactive materials within the radiation area, removing items from the area, or disassembling or modifying any activated component.
- Know the radiation levels and where to position yourself to minimize your dose.
- Only Radiation Workers are permitted in Radiation Areas - no visitors.

Requirements for working include:

- Don't loiter
- Practice keeping your exposure ALARA
- Read your SRPD periodically if you are using one
- If unanticipated elevated radiation levels are indicated as identified by off-scale dosimeter, radiological alarms or other indicators, stop working, alert others working in the area, immediately exit the area and notify RCD personnel.

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Requirements for exiting include:

- Read your SRPD
- Complete the RWP dose tracking form if applicable

Typical locations of Radiation Areas at TJNAF:

- Near activated beamline components in the tunnel/end stations
- Above unshielded service building penetrations
- Labyrinths/shielded passages near the beam enclosure during beam operation

## HIGH RADIATION AREA

Areas where whole body radiation dose rates are >100 mrem/hr at 30 cm from the radiation source. The postings/signs will indicate: "CAUTION - HIGH RADIATION AREA" "RWP Required for Entry" ("Danger" may be used in lieu of "Caution" on some signs).

High Radiation Areas should remain locked and/or have physical barriers established. If the dose rate in the area exceeds 1000 mrem/hr a person may be designated as a "High Radiation Area Watch" to prevent access to personnel. Physical access controls are preferred for High Radiation Areas whenever possible. These physical controls include:

- Locked doors with strictly controlled keys
- Warning devices that inform personnel and supervisors that an entry is being made
- A device that causes the source of radiation to cease upon personnel entry or that prevents entry when the source is present

Requirements for entry:

- Radiation Worker I training
- An RWP is mandatory for High Radiation Areas
- A pre-job briefing is required to enter High Radiation Areas
- SRPDs are required. Additional dosimetry may be required - always check the RWP carefully

Typical locations of High Radiation Areas at TJNAF:

- Near irradiated high power beam dumps
- Near highly activated portions of beamline
- End station beam dump cooling water buildings
- Interlocked beam enclosure when beam is on
- Near operating RF accelerator cavities

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## Hot Spot

A spot (usually small) where the dose rate on contact is greater than 100 mrem/hr and at least five times the dose rate at 30 cm.

Typically, Hot Spots will be located on activated portions of beamline and beamline components. Never handle a Hot Spot without concurrence from the RCD.

## RADIOACTIVE MATERIALS AREA

Areas where radioactive materials are stored or handled. The posting/signs will indicate: "CAUTION - RADIOACTIVE MATERIALS".

The Radioactive Material Area posting is usually accompanied by an RCA designation.

Note: Installed beam line components and hardware are not normally tagged as radioactive material - Always get concurrence from the RCD prior to disassembling/removing such equipment.

The presence of radioactive materials does not always signify a radiological area. Radiological areas are posted based on the potential for radiation *exposure* above certain levels, while Radioactive Materials Areas are posted based on the *quantity* of material. However, in order to maintain control and accountability of radioactive materials, Controlled Areas are usually established for storing them. Removal of radioactive items from these areas requires RCD approval.

Sometimes radioactive materials are stored in non-controlled areas temporarily. This may be the case when exterior dose rates on an item are so low that it presents no significant radiological hazard and no need for personnel dosimetry for working in the area. When these conditions are met, the container or radioactive item itself are considered the Controlled Area boundary, and the item must:

- Be conspicuously labeled as Radioactive Material, and
- Have a Controlled Radioactive Material tag, which identifies the custodian of the material, approved storage location, and its radiological properties.

Typical locations of Radioactive Materials Areas at TJNAF:

- Beam Enclosure
- Areas within EEL and Test Lab
- Designated Radioactive Material Storage Areas within the site Controlled Area

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Summary of Radiation Worker I accessible areas.

Location	Dose Rate Criteria	Posting
Controlled Area	< 100 mrem/yr	Controlled Area, Training or Escort Required for Entry
Radiologically Controlled Area	> 0.05 mrem/hr (>100 mrem/yr)	Radiologically Controlled Area, (or RCA) Dosimetry Required for Entry
Radiation Area	5 mrem/h - 100 mrem/h	Caution Radiation Area
High Radiation Area	> 100 mrem/h	Caution High Radiation Area, RWP Required
Hot Spot	> 100 mrem/h on contact	Caution Hot Spot
Radioactive Materials Area	Radioactive materials above certain activity limits	Caution Radioactive materials

## Other Radiological Areas

The following are areas which Radiation Worker I trained individuals cannot enter:

1. **Very High Radiation Area** - The postings/signs will indicate:  
"GRAVE DANGER - VERY HIGH RADIATION AREA" "Special Controls Required for Entry"
2. **Contamination Area** - The postings/signs will indicate:  
"Contamination Area" "RWP Required for Entry"
3. **Radiography Area** - The postings/signs will indicate: "Radiation Area, Keep Out". Only the radiographic team and associated RCD personnel are allowed entry to these areas.
4. **Airborne Radioactivity Area** - The postings/signs will indicate:  
"Caution, Airborne Radioactivity Area, RWP Required for Entry". There are occasional exceptions for entering Airborne Radioactivity Areas.

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## **Review:**

1. An area posted as a "Radiation Area" has dose rates between \_\_\_\_\_ and \_\_\_\_\_ mrem/hr.
2. Why is the beam enclosure posted as a Radioactive Materials Area?  
\_\_\_\_\_.
3. 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
4. A "Radiation Area" will \_\_\_\_\_ require a RWP. (always, sometimes, never)
5. When moving a component that is known to be radioactive from one location to another - even within an RCA - you should notify the RCD because  
\_\_\_\_\_  
\_\_\_\_\_.
6. List 3 requirements for entry to a High Radiation Area. \_\_\_\_\_,  
\_\_\_\_\_, \_\_\_\_\_.
7. 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.
8. Radiation Worker I trained individuals may not enter areas posted as  
\_\_\_\_\_. (name three)

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## 10.3.2.3 Radiological Work Permits (RWPs)

RWPs are used to establish radiological controls for entry into areas controlled for radiological purposes. With Radiation Worker I training, you may be required to use an RWP. RWPs serve to:

- Inform workers of area radiological conditions.
- Inform workers of entry requirements and/or restrictions on work in the area.
- Provide a means for dose tracking.

There are two basic types of Radiological Work Permits depending on the radiological conditions:

**1. General Radiological Work Permit** - 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. It is valid for up to one calendar year. A special example of such a permit is the General Access RWP required for any work in the beam enclosure. This RWP requires review and signature on the briefing sheet once per calendar year. You should check the continuation sheets (posted at access points) for updates to the RWP frequently.

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

Note: RWPs may be required in addition to OSPs, RCOPs, etc. Always check for RWP requirements prior to beginning work in radiological areas.

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When using a Radiological Work Permit YOUR SIGNATURE INDICATES THAT YOU HAVE READ THE RWP AND UNDERSTAND THE REQUIREMENTS IN IT. If you don't think that the RWP is correct or you don't understand some of the information, don't sign the permit and contact RCD personnel or your supervisor. Workers must obey any instructions written in the permit. Never make substitutions for specified requirements.

- Use blue or black ink to complete the RWP timesheet.
- Make entries legible and complete.
- Sign the timesheet - Do not print your name.
- Correct any errors with one line through, initials and date.

## **10.3.2.4      Radiological Survey Maps**

Survey maps are an important tool to provide you with the locations of significant radiation levels and help you minimize your dose while working in the area. Most RWPs will have associated survey maps included.

Information on the maps may include contact, whole body (readings at 30cm), general area dose rates, and contamination levels if applicable. Dose rates are usually given in mrem/hr.

You should know:

- The locations of low-dose areas
- Where the highest radiation levels and Hot Spots are
- The expected dose rates in your work area

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## 10.3.2.5 Radiological Control Operating Procedures (RCOPS)

Define the scope and limitations to a task or procedure. Typical uses include:

- Handling certain radioactive sources
- Operation of radiation producing machines
- Experimental setups or first-time activities to establish hold-points

## 10.3.2.6 Contamination Monitoring Procedures



Upon exiting some RCAs you may be required to monitor yourself - or "frisk" - for the presence of contamination. Appropriate instruments for this purpose will be staged at areas where there is a requirement for monitoring.

The purpose of using any type of contamination monitoring equipment is to detect and limit the spread of contamination.

### USING A FRISKER

Friskers are beta-gamma detection instruments capable of measuring small amounts of radioactivity on surfaces. To be effective in this, the frisker probe must be held with the "window" facing the surface to be monitored within 1/2" of the surface and moved very slowly covering the entire area. It should take about 2 -3 minutes for a proper "whole body" frisk.

Note: Do not touch or handle the frisker prior to checking your hands unless absolutely necessary.

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To perform a whole body frisk:

1. Verify that the instrument is on, set to the lowest scale, and that background is being detected. Make sure you can hear the audible response.
2. Background must be below 300 cpm (counts per minute) - if possible, survey in an area where the background is less than 100 cpm.
3. If equipped with a response switch, it should be in the "slow" position.
4. Monitor your hands carefully before picking the probe up.
5. Hold the probe within 1/2" of the surface and slowly scan all surfaces of your body, moving the probe no faster than one to two inches per second.
6. While surveying, you should watch the area being surveyed and listen carefully to the audible response for increases in the click rate. There is no need to watch the meter - the audible response is faster, and you should pay attention to where you are surveying.
7. Survey the body in a methodical manner - a typical order is:
  - a. head - check carefully around face, nose, mouth
  - b. neck, shoulders, arms
  - c. chest, abdomen
  - d. back, hips, seat of pants
  - e. legs - check knees carefully
  - f. feet - check soles of shoes carefully
8. Check your dosimetry and any personal items such as notebooks, pencils, pens.
9. Return the probe to the holder in a way that allows the next user to check hands without touching the probe.

Contamination is indicated by an increase in the count rate. When you hear an increase, pause for a moment over the area being surveyed. Do not rely solely on the instrument's alarm function to alert you to potential contamination.

If contamination is indicated, remain in the area and notify the RCD immediately. Minimize potential cross-contamination of other items or people. While awaiting RCD personnel, continue to frisk to see if the contamination can be localized to a specific area.

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## 10.4 Your Responsibilities Regarding Radiological Controls

It is each worker's responsibility to read and comply with all the information identified on radiological postings, signs and labels. Disregarding any of these postings or warnings can lead to unnecessary or excessive radiation exposure and/or personnel contamination. *Never take it upon yourself to relocate or remove a radiological placard, label, sign, rope or other boundary.*

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

It is important for everyone to try and minimize the amount of radioactive waste that is produced when working. Key methods for minimizing the amount of radioactive waste include:

- Minimize the materials used for radiological work.
- Take only the tools and materials you need for the job into the Radiologically Controlled Area.
- Unpack equipment and tools in a "clean" area to avoid bringing excess material into an RCA.
- Segregate radioactive waste from non-radioactive waste - Special yellow and black bins located inside the beam enclosures are to be used for disposal of items known or suspected of being radioactive. Only items that were brought into the accelerator enclosure as "clean" and are known not to be radioactive should be put in the "clean" trash containers. Do not put clean waste, packing material and other refuse in the yellow and black bins.
- Minimize the amount of mixed waste generated (mixed waste refers to materials that are classified as hazardous chemicals and are radioactive).
- Use good housekeeping techniques.

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## **Review:**

9. 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 \_\_\_\_\_.

10. The two main types of RWPs are \_\_\_\_\_ and \_\_\_\_\_.

11. In the case of a job specific RWP, what two groups are involved in the initiation of the permit?

\_\_\_\_\_ and \_\_\_\_\_.

12. Among the types of information found on an RWP are (name four):

\_\_\_\_\_.

13. RWPs are always required in:

- a. a Radiation Area
- b. a Controlled Area
- c. a High Radiation Area
- d. all the above

14. Your signature on the RWP indicates that you have \_\_\_\_\_ the RWP, and that you \_\_\_\_\_ and will follow the \_\_\_\_\_ in it.

15. Why is it particularly important that people follow RWP requirements closely?

- a. So TJNAF won't be sued
- b. Because there are potentially lethal conditions in RWP areas
- c. Because failure to do so could cause major damage to accelerator components
- d. Because RWPs are used where there are significant radiological hazards, and maintaining control over activities in the area is the only way to ensure that the hazard to personnel is minimized

16. You can help minimize 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

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17. 100 cpm on a frisker relates to approximately how much radioactive material?
  - a. about 100 mrem
  - b. about 100 dpm
  - c. about 1000 dpm
  - d. about 100 curies
  
18. Where can you get information about the radiation levels in your work area?
  - a. Radiological survey maps
  - b. An RCD Technologist
  - c. Radiation Work Permits
  - d. All the above

## ANSWERS TO UNIT 10 REVIEW QUESTIONS

1. 5/100
2. because of the buildup of activated material in the components in the enclosure
3. d.
4. sometimes
5. Depending on the radiation levels on the material, you may be creating a "moving Radiation Area" that must be properly posted. Also, the placement of the material near the boundary to a radiation area or RCA may impact the radiation levels outside the area.
6. Level I training (with special briefing) or level II training, Radiation Work Permit, Supplemental dosimetry
7. 30 cm (about 1 foot), whole body
8. very high radiation area, contaminated area, airborne radioactivity area
9. radiological conditions, requirements, tracking
10. general, job-specific
11. the group performing the work, the RCD
12. dosimetry requirements, protective clothing requirements, stay time limits, nature of the work, radiological conditions, radiological job coverage requirements (others)
13. c.
14. read, understand, requirements
15. d.
16. e.
17. c.
18. d

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## 11 Emergencies, Alarms, and Responses

Equipment which indicates the status of the accelerator and equipment which monitors for unusual radiation levels is placed in strategic locations throughout TJNAF. It is essential for radiological workers to be able to identify the equipment alarms and status indicators and respond appropriately to each.

### 11.1 Personnel Safety System

The TJNAF Personnel Safety System (PSS) protects personnel from exposure to high radiation levels and other hazards in the accelerator enclosure associated with operation of the electron beam. PSS access controls include magnetically locked and interlocked doors and gates, keybanks for controlled accesses, and status indicators. Other functions of the PSS include direct beam sensing and termination capabilities, radiation monitoring, and emergency shut off switches. Status displays you should recognize include:

#### Machine state status indicators



These automatic signs are located at each main access point to the beam enclosure. **Access to the enclosure is permitted only during Restricted Access or Controlled Access modes.** You may enter only if all other requirements for entry are met. Never attempt to enter the enclosure unless you are sure the accelerator is in a safe state.

#### Magenta beacons



The magenta beacon signifies a condition in which access to an area is not permitted (when interlocks are engaged). These beacons are located at access points which do not have machine state status indicators. These beacons may also be used in off-site areas to warn of operational radiation producing devices. The beacon will be accompanied by radiological postings indicating the type of radiological area denoted by its operation. NEVER attempt to enter an area designated by an operating beacon.

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## Run/Safe box

These indicate the status of the accelerator during tunnel/hall access. Run/Safe boxes are located strategically within the beam enclosure and provide an indication of the machine state as well as a means to terminate unsafe conditions in the event of an accident or other failure. When you enter the beam enclosure, always take note of the Run/Safe boxes.



The Run/Safe box has the following indicators:

**GREEN "Safe"** - Safe for occupancy under normal "Restricted Access" conditions. Access by trained, authorized personnel.

**YELLOW + GREEN "Operational" + "Safe"** – Safe for occupancy under "Controlled Access" conditions by special interlock key control.

**RED "Unsafe"** – "Exclusion Area", no access by personnel under any circumstances!

A simple rule to remember regarding the Run/Safe boxes is:

*The box must always indicate SAFE unless you have an interlocked access key (used for Controlled Access) - in this case the box will indicate OPERATIONAL/ SAFE.*

The box should NEVER indicate UNSAFE while an area is occupied.

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If you are in the beam enclosure and the Run/Safe Box status indicator is incorrect for your level of access you should:

1. hit the red “Emergency Stop” button
2. stop work
3. warn others in the vicinity
4. exit the area leaving tools and equipment behind
5. report to the Crew Chief immediately
6. follow the Crew Chief’s instructions carefully

## Controlled Area Radiation Monitors (CARMs)

CARMs continually monitor radiation levels around the accelerator facility and provide a readout on the CARM console in the Machine Control Center. Each CARM has a pre-established alarm set point which, if exceeded, will cause immediate termination of the beam. The CARMs monitor for unusual radiation levels in occupied areas adjacent to the accelerator tunnel.



CARMs are located in key areas at appropriate intervals for a range of operating conditions. In some cases it will be necessary to have the detector(s) of a CARM in your immediate work area. Always check the OSP or TOSP for any such requirements prior to work in service buildings or other areas near the beam enclosure. If a specific location for a CARM probe is required by an Operational Safety Procedure or an RWP, an Assigned Radiation Monitor or a member of the Radiation Control Department will relocate the CARM probe(s). Only RCD personnel or an ARM are allowed to relocate CARM probes.

If, in your work area, you encounter a CARM in a “High Alarm” state, you should:

1. stop work
2. warn others in the vicinity
3. exit the area leaving tools and equipment behind
4. call the Crew Chief immediately
5. remain out of the area until the Crew Chief gives permission to return

The “High Alarm” condition is indicated by an audible alarm and a red light on the CARM control box. This alarm state results in removal of beam permit. (The yellow light indicates a probe failure. The yellow light should also be reported to the Crew Chief, but it does not constitute an emergency.)

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**Disregarding radiological alarms, status indicators, written or verbal instructions, or radiological postings can lead to disciplinary action, excessive personnel exposure, uncontrolled spread of radioactive material, personal injury, or, in severe cases, death.**

## 11.2 Emergency Situations

Working in a radiological environment requires more precautionary measures than performing the same job in a non-radiological setting. This premise is especially true if an emergency arises during radiological work.

Radiological emergencies include improper status indicators or change of status indicator on Run/Safe boxes; fire in a radiological area; high radiation exposure to personnel; injury or loss of life in a radiological area; and damage, abuse, or loss of radioactive material or sources.

Responsibility for dealing with an emergency initially rests with the person discovering it. Your responsibility regarding discovery of a radiological emergency includes:

- Taking appropriate action to protect life, property, and the environment.
- Warning others in the area of the situation and minimizing your own radiation exposure.
- Making the appropriate notifications.

### 11.2.1 Beam-on Emergency

The Crew Chief has overall responsibility for safety and coordinating emergency response on the accelerator site.

In the event of a beam-on emergency follow the steps below:

1. Stop work or activity in the location of the suspected accident. If in the accelerator tunnel, press the red Emergency Stop button on the nearest Run/Safe box. Make a mental note of your location and exit the area immediately. Warn any others in the area of the situation.
2. Seek immediate medical attention for any injured individual - dial 911 and request assistance. An injured individual who is not conscious or ambulatory should only be moved by medical personnel. Provide any information you know regarding radiological conditions to the emergency services contact.
3. Report to the Crew Chief at the MCC and explain what occurred and any actions you've taken. Follow the instructions of the Crew Chief carefully.

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4. 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 from your person. Compliance with the Crew Chief will provide important information regarding potential radiation exposure.
5. If uninjured, remain at the location designated by the Crew Chief until RCD personnel make a determination of the extent of potential exposure.

## **11.2.2 Non-Accelerator Radiological Emergency**

In the event of a radiological emergency involving spills or loss of radioactive material, potential excessive or unmonitored personnel exposure, or spread of contamination to personnel or uncontrolled areas, the RCD should be notified.

All security guard posts, the MCC, and the Experimental Hall Counting House have up-to-date emergency call-out lists which can be used to contact the RCD.

In the event of a spill or other loss of control of radioactive material, remember the acronym SWIMN.

**S** - Stop the spill - for example upright an overturned container that is causing a spill.

**W** - Warn others - make sure other people in the area know what has happened.

**I** - Isolate the area - close the doors or use convenient items to form a barrier.

**M** - Minimize your exposure - once you have taken initial steps, move away from the area.

**N** - Notify RCD personnel - await RCD personnel at a safe distance.

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## **11.2.3 Medical Emergency**

In the event of an injury in a radiological area call 911 immediately. The 911 emergency number can be reached from any TJNAF phone - there is no need to dial 9 for outside access. After calling 911, you should also notify TJNAF emergency personnel by dialing 4444.

If you are capable, you may administer first aid to the injured person, even if they are located in a Contamination Area or other radiological area. However, remember that an injured person should not be moved unless there is another imminent hazard present (e.g. risk of electrical shock or fire).

Call 911 to report radiological emergencies only when:

- There are, or could be injuries involved
- There is a fire

## **11.2.4 Considerations in Rescue and Recovery Operations**

If emergency personnel require access to the accelerator enclosure, it is important that their entry not be delayed. The normal administrative controls that we follow daily are not applicable to emergency situations. For example, if firefighters need access to the enclosure, the beam would be terminated and the accelerator would be placed in a safe condition. At this point, the firefighters would be allowed access. Entry for short periods under these conditions is not expected to result in significant radiation exposure. It is very unlikely that any emergency responder could receive a dose that approaches the TJNAF design goal for Radiation Workers during an emergency entry. Radiological conditions can be determined following the emergency entry in order to calculate doses to the emergency responders.

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## **11.2.5 Emergency Exposure Guidelines**

### Planned Special Exposures (PSE)

In some cases where a planned event is anticipated to cause personnel to exceed the routine dose limit of 5 rem, and other options are not practicable, a Planned Special Exposure may be necessary. These events are not considered emergencies but are unusual and are not expected to be repeated. The total dose to an individual under these circumstances must not exceed 10 rem, including all other exposure received for the year.

### Lifesaving and Rescue Operations

In extremely rare cases, emergency exposure to high levels of radiation may be necessary to mitigate injury, death or major property damage. These operations will be guided by an emergency response director. Careful judgment must be used during such situations of substantial personnel risk.

The DOE emergency guidelines for such personnel are as follows:

- Protecting major property - 10 rem
- Lifesaving or protection of large populations - 25 rem - or greater than 25 rem when:
  - only volunteers are used
  - risks are thoroughly assessed
  - personnel are fully briefed on magnitude of risk

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## **Review:**

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. there would be a loud hissing sound
  - d. a flashing blue light
  
2. The worst-case radiation accident scenario at TJNAF 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 radiation emergency on the accelerator site, the first notification (following a 911 call, if necessary) should be to the \_\_\_\_\_.
  
4. CARMs monitor radiation levels:
  - a. in the interlocked beam enclosure
  - b. in occupied areas near the beam enclosure
  - c. in the EEL building
  
5. If a CARM alarms, workers in the area should:
  - a. ignore it, the Crew Chief already knows something is wrong
  - b. stop work, warn others, leave the area, and notify the Crew Chief
  - c. call the RCD
  - d. hit the "acknowledge" button so the beam can be turned back on
  
6. The rotating magenta beacon \_\_\_\_\_ (is/ is not) an emergency alarm. These beacons alert personnel to the existence of \_\_\_\_\_ radiation levels.
  
7. If a person is located in a High Radiation Area and experiences a severe traumatic injury, the primary concern of ALL by-standers, safety professionals, and rescue personnel is:  
\_\_\_\_\_.

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8. If you encounter a spill of contaminated water, you should:

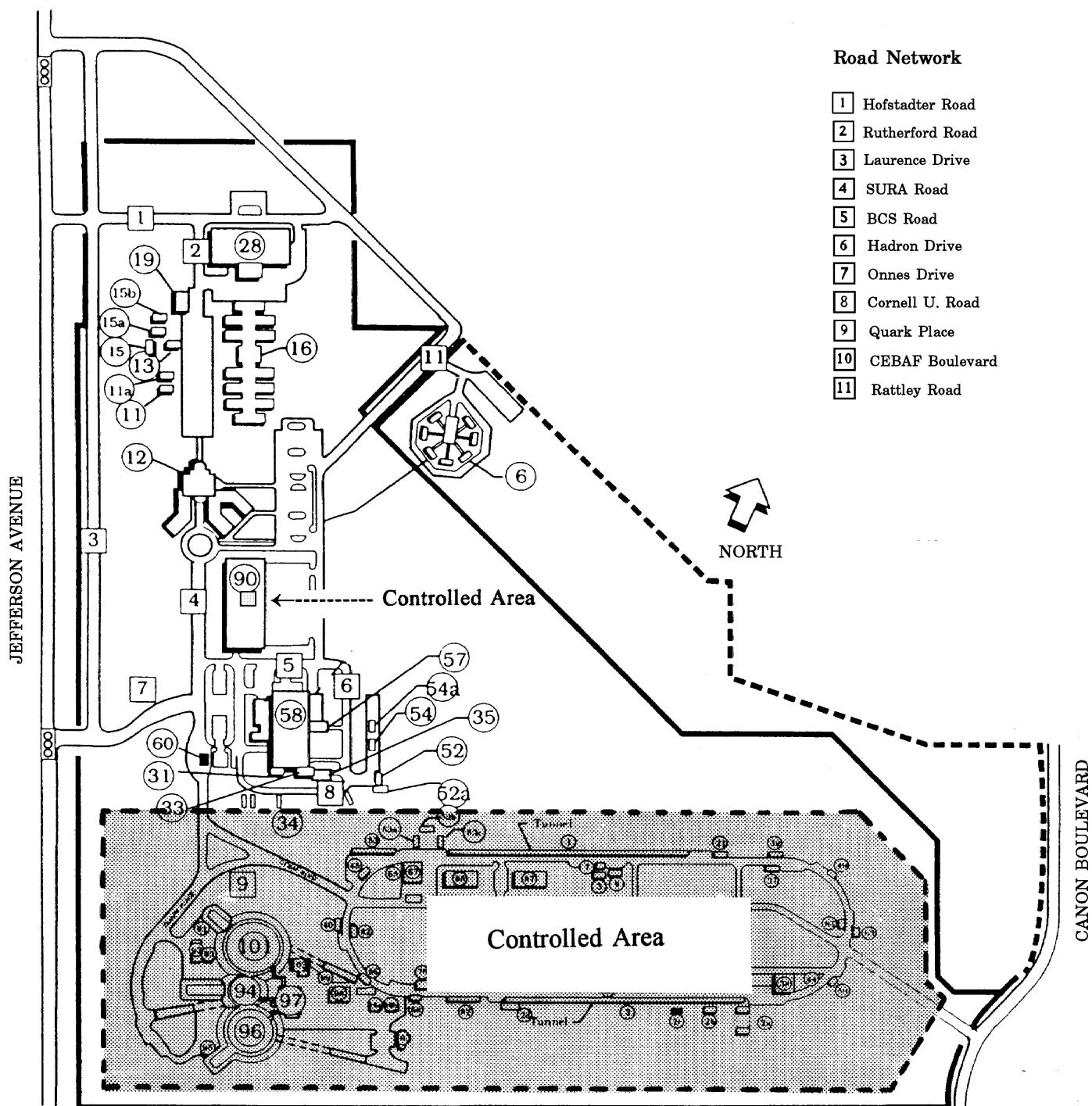
- a. try to stop the spill if you can without making the situation worse
- b. warn others in the area to stay away from the spill area
- c. isolate the area, call the RCD, and await their arrival at a safe distance
- d. all of the above

### ANSWERS TO UNIT 11 REVIEW QUESTIONS

1. b.
2. b.
3. Crew Chief
4. b.
5. b.
6. is not, potentially high or intermittent
7. attendance to the injury, i.e. lifesaving measures, stabilization of the person's condition, etc.
8. d.

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## Appendix A: TJNAF Site Controlled Area



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## Appendix B: Instructions for Practical Factors Evaluation

The intent of the practical factors exercise is to ensure that radiation workers can apply their knowledge of radiation safety by participating in an evaluated scenario designed to check for key elements of proper radiological work practices.

The practical elements that each participant should demonstrate are:

1. Identify and comply with RWP requirements.
2. Record appropriate information on an RWP.
3. Select and properly wear dosimetry as required by the RWP.
4. Enter a simulated radiological area and demonstrate ALARA techniques while carrying out a simulated task.
5. Respond properly to abnormal radiological conditions and alarms.
6. Monitor for personnel contamination in accordance with instructions.

Your instructor will provide a briefing on the simulated RWP prior to beginning the evaluation. He or she will identify and demonstrate key elements to be performed. You should ask questions during this demonstration and ask for practice if you are unsure about radiological information or how a particular element is to be carried out. Your instructor will not coach or show you how to perform the tasks once your evaluation has begun.

Suggestions for Preparation:

- Read the RWP carefully, and make sure you have all your questions about it answered. Study the survey map.
- Form a mental picture of the area and the associated radiation levels; keep this in mind when working in the area.
- Take note of the highest dose rates in the area, and based on these, determine what the area posting should be. When preparing to enter the area, check all the postings to make sure they are appropriate for the levels noted.
- Take note of any areas from which you are restricted based on the RWP limitations or posting designation.
- Make sure you bring any discrepancies you note in postings or conditions in the area to the attention of the instructor.
- Be alert for any conditions which do not seem appropriate for the area.
- To the extent possible, act as you would in an actual radiological area - make sure you demonstrate ALARA by your actions. Don't linger around high radiation levels, keep your dose to a minimum.

## **TJNAF Radiation Worker Training**

### **Glossary**

**Accelerator:**

A device that increases the momentum and, therefore, the energy of charged particles such as electrons or protons.

**Access Control System:**

Engineered and/or administrative systems that limit radiation dose to personnel by managing and limiting entry to an area.

**Activation:**

The process of making a material radioactive by bombardment with neutrons, protons, or high energy photons.

**Activity (radioactivity):**

The rate at which a source emits radiation. Activity is measured in terms of the number of disintegrations that take place in some time period (e.g. disintegrations per second). The special unit for activity is the curie. One curie (Ci) is equal to 37 billion ( $3.7 \times 10^{10}$ ) disintegrations per second.

**Acute Dose:**

The absorption of a relatively large amount of radiation over a short period of time.

**Acute Radiation Syndrome (ARS):**

The complex of symptoms brought about by excessive whole body exposure to radiation. ARS is the result of an acute dose; some early visible symptoms may include nausea, vomiting, and fatigue, followed by a predictable progression of other deterministic effects depending on the total dose.

**Administrative Controls:**

Procedures and activities which involve human actions that are designed to minimize or control personnel radiation exposure. Examples of administrative controls are Radiation Work Permits, sweep procedures, and TOSPs.

**ALARA:**

As Low As Reasonably Achievable. Making every reasonable effort to maintain exposures to radiation as far below the dose limits as is practical, taking into account the state of technology and other societal and economic considerations, including the benefit of the radiation producing activity.

**Alpha Particle:**

A positively charged particle ejected spontaneously from the nuclei of some radioactive atoms. It is identical to a helium nucleus - it contains two protons and two neutrons.

Assigned Radiation Monitor (ARM):

A person who has received training beyond the Radiation Worker I course in the use of radiation protection instrumentation and administrative procedures for controlling exposure to radiation and handling of radioactive material.

Atomic Number (Z number):

The number of protons in the nucleus of an atom.

Atomic Weight: See mass number.

Attenuation:

The process by which radiation is reduced in intensity when passing through some material. It is the combination of absorption and scattering processes.

Background Radiation:

Radiation present in the environment to which all people are exposed. Background radiation comes from natural sources of radiation, and from manmade sources such as global fallout and certain consumer products.

Beam:

A flow of electromagnetic or particulate radiation that is either unidirectional by nature, or has been collimated or restricted to a small solid angle.

Beam Enclosure:

The structure which houses the accelerator and experimental target areas. It is interlocked during accelerator operation to prevent personnel access.

Beamline:

The vacuum chamber in which the beam travels (generally includes associated components of beam transport, such as magnets, beam dumps, accelerating cavities, etc.).

Beta Particle:

An energetic electron or positron which is emitted from the nuclei of some radioactive atoms.

Bremsstrahlung:

Photon radiation (continuous x-rays) produced by the deceleration of charged particles as they pass through matter.

Charged Particle:

An ion. A particle carrying a positive or negative electric charge.

Chronic Dose:

The absorption of a relatively small amount of radiation over a long period of time.

Collective Dose:

The sum of the individual doses received in a given period of time by a specific group of people.

See person-rem.

Collimator:

A device which limits the size, shape, and direction of a radiation beam.

Contamination:

The deposition of unwanted radioactive material (usually in an easily removable form) on surfaces of structures, areas, objects, or personnel.

Controlled Area:

Any area where access is controlled to ensure the radiological safety of personnel. Controlled Areas contain radiological hazards which are identified by specific postings. Personnel who work only in a Controlled Area are not expected to receive a dose of more than 100 mrem/yr.

Controlled Area Radiation Monitor (CARM):

A radiation detection system which is interlocked to the Personnel Safety System and designed to turn off the electron beam if radiation levels exceed pre-established set points.

Cumulative Dose:

The total dose received by an individual over a period of time.

Curie: See activity.

Daughter Product (progeny):

Nuclide that is formed by the radioactive decay of some other nuclide. For example, the radionuclide Cobalt-60 decays to the stable isotope Nickel-60. See nuclide and isotope.

Declared Pregnant Worker:

A woman who, for the purpose of limiting her exposure to radiation, has voluntarily informed her employer, in writing, of her pregnancy and the estimated date of conception.

Deep Dose:

Applies to the measurement of external, whole body radiation exposure. Specifically, it is the equivalent dose at a tissue depth of 1 cm. See whole body.

Detector:

A material or device that is sensitive to radiation and can produce a response signal suitable for measurement or analysis.

Deterministic Effect:

A biological effect which becomes more severe with an increase in dose. These effects usually have thresholds or minimum values, below which the risk of experiencing the effect is considered to be zero.

Dose:

A generic term for the amount of radiation absorbed.

Dosimeter:

A device or instrument for measuring integrated (or cumulative) dose to an individual.

Electromagnetic Radiation:

Radiation having no mass or charge. A traveling wave resulting from changing electric and/or magnetic fields. See photon.

Electron:

An elementary particle with a unit negative charge and a mass 1/1837 that of a proton.

Electrons surround the positively charged nucleus and determine the chemical properties of an atom.

Electron Volt (eV):

Unit of energy equivalent to the energy gained by an electron in passing through a potential difference of one volt. It is used to quantify the energy or momentum possessed by high energy particles or electromagnetic radiation. Typical ionizing radiations are in the thousand (keV) or million (MeV) electron volt range.

Engineered Controls:

Equipment, structures, and devices which limit or prevent radiation exposure to personnel with little or no human intervention. These controls may be passive (e.g. shielding) or active (e.g. interlocks) in nature.

Equivalent Dose:

The product of absorbed dose (in rad) in tissue and radiation weighting factor. Equivalent dose is measured in rem. It is a description of the dose received by a person in terms of biological effect, rather than strictly energy absorbed.

Exposure:

Term used generally to describe receiving radiation dose.

-And-

A measure of the ionization produced in air by x or gamma radiation. The unit for exposure is the Roentgen (R). Whole body exposure to 1 R of x or gamma radiation results in an equivalent dose of approximately 1 rem.

Gamma Radiation:

High energy, short wavelength electromagnetic radiation emitted from the nucleus. Gamma radiation frequently accompanies beta and alpha emission during radioactive decay.

Genetic Effect (Heritable Effect):

An effect which occurs in a future generation of an exposed person.

High Radiation Area:

Any area, accessible to individuals, in which radiation levels could result in an individual receiving an equivalent dose to the whole body in excess of 0.1 rem in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

Interlock:

Any automatic sensing device that causes a radiation producing machine to shut off or prevents access to the beam while it is present.

Ion: See charged particle.

Ionization:

The separation of orbital electrons from an atom.

Ionizing Radiation:

Radiation which has enough energy to ionize the matter through which it passes.

Isotope:

One of two or more atoms of a given element having different numbers of neutrons. Thus, carbon-12, carbon-13, and carbon-14 are isotopes of the element carbon. The numbers 12, 13, and 14 denote the total number of protons and neutrons in the isotope. See nuclide.

Linear Accelerator (Linac):

A device used to accelerate charged particles in a straight line.

Mass Number:

The total number of nucleons (protons and neutrons) in the nucleus of an atom.

Neutron:

An elementary particle with no electrical charge which has approximately the same mass as a proton.

Nucleus:

The small, central region of an atom consisting of protons and neutrons (nucleons). The nucleus contains essentially all of the mass of the atom.

Nuclide:

General term referring to all known isotopes, groups of isotopes, or a single isotope.

Operational Safety Procedure (OSP):

An administrative control measure which describes hazards present and what controls are in place to mitigate or minimize the hazards. OSPs are used during routine operations. Generally associated with an operational instruction rather than a purely safety-related procedure. See TOSP.

Personnel Safety System (PSS):

An active engineered control system comprised of interlocks, sensors, and other devices which prevents personnel access to the beam enclosure and/or terminates accelerator operation in the event that trip points are exceeded or interlocks are triggered.

Person-rem:

The unit of collective dose. The person-rem total for a given job and time period is the sum of all doses received by all persons involved in the work for that period. See collective dose.

Photon:

A quantum (discrete packet) of electromagnetic energy. It is customary to refer to photons that originate in the nucleus (during radioactive decay) as gamma-rays, and those which originate within the electron field as x-rays.

Positron:

A positively charged beta particle.

Prompt Radiation:

Particulate or electromagnetic radiation resulting from the accelerator beam or interaction of the beam with surrounding matter. Prompt radiation ceases immediately after shut off of the beam.

rad:

Radiation Absorbed Dose. The special unit of absorbed dose used to quantify the amount of radiation energy absorbed per unit mass of any material. One rad is equal to an absorbed dose of 100 ergs/gram or 0.01 J/kg.

Radiation Area:

Any area, accessible to individuals, in which radiation levels could result in an individual receiving an equivalent dose to the whole body in excess of 0.005 rem in 1 hour at 30 centimeters from the source or from any surface that the radiation penetrates.

Radiation Weighting Factor ( $W_R$ ):

A modifying factor used to calculate the equivalent dose from the average tissue or organ absorbed dose. The value of the radiation weighting factor for a given type of radiation is based on the biological effectiveness of that radiation in creating damage to tissues.

Radiation Worker:

A person who has received specific training and qualifications to make unescorted accesses into radiological areas and perform work of a radiological nature.

Radiation Work Permit (RWP):

An administrative control measure consisting of a set of requirements for protective equipment, dosimetry, entry and stay time restrictions, and work control measures used to limit personnel exposure during work in certain radiological areas.

Radioactive Material:

Any material containing unstable atoms which decay with the release of ionizing radiation.

Radioactive Materials Area:

An area in which radioactive materials are used, stored, or handled.

Radiological Area:

Any area requiring posting as a Radiation Area, High Radiation Area, Very High Radiation Area, Contamination Area, High Contamination Area, or Airborne Radioactivity Area.

Radiologically Controlled Area (RCA):

Any area where a person could receive a dose in excess of 100 mrem/yr.

Radionuclide:

A radioactive isotope of an element which decays spontaneously, emitting radiation.

rem:

Roentgen equivalent man. The special unit of any of the quantities expressed as equivalent dose. The unit used to express the amount of biological harm done from chronic exposure to ionizing radiation. The equivalent dose in rem is equal to the absorbed dose in rad multiplied by the radiation weighting factor  $W_R$ . The dose measured in rem is not a physical quantity due to the application of the weighting factor. It is an expression of relative risk.

Residual Radiation:

Radiation resulting from the decay of activated material within the accelerator. Residual radiation persists after beam shut-off, and may contribute significantly to the overall dose to radiation workers.

Roentgen:

The special unit for exposure. That amount of gamma- or x-rays which produce ions carrying one electrostatic unit of charge in one cubic centimeter of dry air. See exposure.

Run-Safe Box:

A device which is interlocked to the Personnel Safety System (PSS) used to display the accelerator machine state and visually warn of an unsafe condition. When armed, pressing the red button on the box causes the PSS to stop the beam.

Self Reading Pocket Dosimeter (SRPD):

Any type of dosimeter which allows the user to directly read the exposure from the device. Examples of SRPDs are pocket ion chambers, neutron bubble dosimeters, and digital electronic dosimeters.

Shallow Dose:

Equivalent dose at a tissue depth of 0.007 cm. Shallow dose applies to the skin, not to the whole body.

Somatic Effect:

An effect which occurs in an individual or population exposed to radiation (as opposed to effects which occur in future generations).

Stochastic Effect:

Health effects which occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold.

Examples of stochastic effects are cancer incidence and heritable effects.

Sweep or Search:

A physical search performed concurrent to establishing an interlocked state within the beam enclosure prior to operating the accelerator.

Temporary Operational Safety Procedure (TOSP):

An administrative control measure which describes hazards present and what controls are in place to mitigate or minimize the hazards. TOSPs are used during non-routine operations or temporary configurations of equipment or systems such as special tests or commissioning activities.

Teratogenic Effect:

An effect which occurs in an embryo/fetus exposed to radiation while in the womb.

Very High Radiation Area:

An area where the dose rate exceeds 500 rad/hr at one meter from the source. At Jefferson Lab, a more conservative definition is used - an area where the whole body dose rate is (or might be) above 5000 mrad/hr. See whole body and whole body dose rate.

Whole Body:

The portion of the body consisting of the head, trunk and major blood forming organs extending to the arms just below the elbow and the legs just below the knee. Whole body dose occurs when any of these portions of the body receive a deep dose.

Whole Body Dose Rate:

Radiation level measured at a point 30 cm (~ 1 foot) from the source of radiation or from any surface through which radiation emanates.

X-rays:

Penetrating electromagnetic radiation (photons) with a wavelength much shorter than visible light.