Introduction

If you have just accepted a position working with radiation sources, you have things to do to prepare. What is the next step? First you will need to know what will you be working with and how do you protect yourself as well as others. Typically, this requires training as a Radiation Worker. That will be you. Second, where do you receive the training, how long is it and what are your responsibilities?

We are going to answer all of these questions in the follow text. Hopefully, you will have a performance-based training along with this text to help you acquire the knowledge, skills and abilities to work safely and perform the tasks you are assigned to do.

A common program where a general laboratory worker who is handling radiation sources can be found with many university programs. They are also found in research laboratories and medical institutions. There are too many to list here and would be a waste of your time to read them. Let’s just assume you are at a university working in the laboratory handling radioactive materials. Working with x-ray systems or Class III or IV lasers may be administered the same way.

The researcher (generally a faculty member and most likely your supervisor) has an authorization in his/her name. That means he/she has a permit. This is much like a license, although the actual license is held by the Radiation Safety Officer in the name of the institution. The researcher you are working for is most likely one of several or many others with an authorization under that license.

The researcher must document (record) specific activities. These records are mandated by a regulatory authority. These documents are legal records. They typically tell what is to be recorded in very general terms and not the specific information. This can be very vague for the researcher (who is your supervisor). If he/she does not understand what has to be documented, how can you? The interpretation of the regulations and the program is a responsibility of the Radiation Safety Officer. Frequently there is a Radiation Safety Manual. In general, these are not any more detailed in what you have to perform then the regulations. For guidance, you may need to go to the Radiation Safety Officer.

Some well-developed training programs include a 40-hour performance-based training program. Most programs are still inventing this wheel. The materials in this text were derived from such a program.

A. **Program Administration**

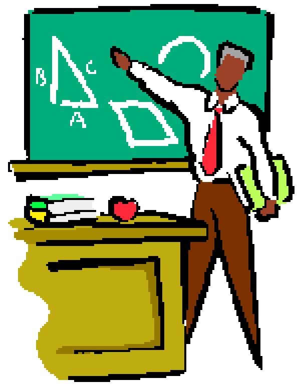
   The institution submits an application to the regulatory authority. This documentation describes what will done with the (radiation) sources, how it will be handled, controls in place to protect people and the environment and records that will be kept. If the regulatory agency feels that they have sufficient controls to administer the program, they issue a license. All documents identified in the regulatory license are a part of the license. This license will also identify who is the Radiation Safety Officer. Larger programs may also have a Radiation Safety Committee. The application will describe (in very general terms) what training will be implemented.

   The regulatory authority will inspect the program at different intervals to see if the institution is following the commitments they made in the application and regulations that governed the use of the radiation sources.

   Typically, a Radiation Safety Committee will review the application of a researcher and review his/her background to see if they wish to authorize the use the radiation sources. If there is no committee than the Radiation Safety Officer completes this process. A committee must meet at least quarterly but can meet more frequently. The Radiation Safety Officer provides a review of the application and provides a recommendation to the Committee. The Radiation Safety Officer reviews programs (perform inspections) in the institution just like the regulatory authority. The Radiation Safety Officer, the Chairman of the Radiation Safety Committee and the President of the institution are personally liable for the program. If the Committee provides an authorization to a researcher, that researcher will also be personally liable.

   Specific records must be kept by the researcher for the sources he/she is authorized. Typically, this includes inventories (cradle to grave), storage, surveys and training. The Radiation Safety Officer reviews these records to ensure they are adequate for the program. It is very common for the researcher to assign these tasks to one of his/her radiation workers. That maybe you. If the researcher is unaware of his/her responsibilities, it will be difficult for you to assume these duties.

B. **Knowledge, skills and abilities training**



If you were going to write a software program to track accounting records for an activity, you will need to know what are accounting records, which are required, how detailed the records must be and how to write software in the language expected. Well, you have to do the same thing as a radiation worker. You will need an understanding of:

- Radiological Fundamentals
- Biological Effects
- Radiation Limits
- ALARA Program
- Personnel Monitoring Programs
- Radioactive Contamination Control
- Radiological Posting and Controls
- Radiological Emergencies
- Internal Control
- Radiological Contamination
- Commonly Used Radionuclides
- Preparation of Work Areas and Materials
- Conduct of Work
- Personal Protective Equipment
- Monitoring for Contamination
- Release of Materials
- Decontamination
- Portable Surveys Meters and Counting Systems
- Use of Fume Hoods and Glove Boxes
- Storage and Containment
- Radioactive Waste Management
- Animal Facilities
- Gamma-
- Cell Irradiators
- Sealed Sources
- X-Ray Sources

These are the topics in this text. For the best results, this text should be used along with performance-based training. As an example; when you are performing a contamination survey you will use a survey instrument to locate contamination and perform a wipe of the surface area. The wipe samples are counted in some system and will provide information about the contamination observed. A performance-based training will have you perform such a survey, interpret the results and document the information. A trained instructor will let you know how accurate you are with the activity. Did you perform the survey without contaminating yourself, did you identify the contaminated areas and the clean areas?

The text is not intended to teach you to be a Health Physicist, just sufficient enough to know what you are working with and how to protect yourself. A Health Physicist is an individual who is trained and experienced in Radiation Safety.

Section 1. Radiological Fundamentals

LEARNING OBJECTIVES:

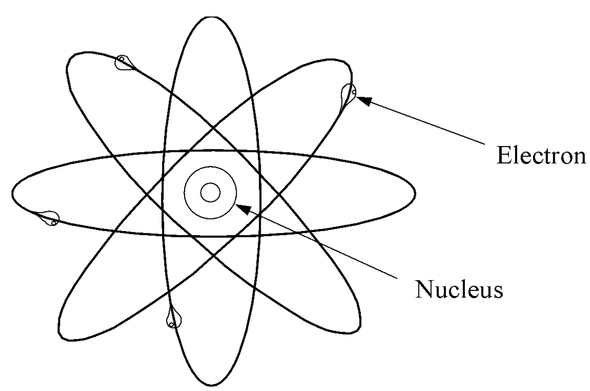
IDENTIFY the three basic particles of an atom.
DEFINE ionization.
DEFINE ionizing radiation, radioactive material and radioactive contamination.
DISTINGUISH between ionizing radiation and non-ionizing radiation.
DEFINE radioactivity and radioactive half-life.
STATE the four basic types of ionizing radiation.
IDENTIFY the following for each of the four types of ionizing radiation:

- a. Physical Characteristics
- b. Range/Shielding
- c. Biological Hazard(s)

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

A. ATOMIC STRUCTURE

The basic unit of matter is the atom. It is made up of neutrons, protons, and electrons. The central portion of the atom is the nucleus, which consists of protons (with a positive electrostatic charge) and neutrons (no charge). Electrons orbit the nucleus (with a negative charge), see figure 1.1. The word “atom” comes from the Greek word meaning “invisible particle.”



Nucleus = Protons + Neutrons

FIGURE 1.1 - THE THREE BASIC PARTICLES OF THE ATOM

Certain atoms, because of an excess of energy or mass or both, are unstable. This instability is due to an unbalanced ratio between the neutrons and the protons in the nucleus of the atom. Atoms strive to stay or become electrically balanced or stable. In order to reach stability these atoms give off or emit the excess energy or mass (waves or particles) that we call radiation.

Nuclear force is what holds the protons and neutrons together in the nucleus of the atom. This force is associated with the neutrons. If it did not do this, everything in the universe would fall apart. So nuclear simply means, “having to do with the nucleus.”

1. Protons

- Protons are located in the nucleus of the atom.
- Protons have a positive electrical charge. The mass of the proton is 1.00728 amu (atomic mass units).
- The number of protons in the nucleus determines the element. Example: Hydrogen has one proton in the nucleus, Helium has two protons, etc.
- If the number of protons in an atom change, the element changes.

2. Neutrons

- Neutrons are located in the nucleus of the atom.
- Neutrons have no electrical charge. The mass of the neutron is 1.00876 amu.
- Atoms of the same element have the same number of protons, but can have a different number of neutrons. Example: Hydrogen can have zero, one or two neutrons in the nucleus.
- The atoms of the same element that have the same number of protons but different numbers of neutrons are called isotopes.
- Even though isotopes have the same chemical properties, the nuclear properties can be quite different.

3. Electrons

Electrons orbit the nucleus of an atom.

Electrons have a negative electrical charge.

Electrons determine the chemical properties of an atom.

4. Charge of the atom

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

- No charge (neutral) - If the number of electrons equals the number of protons, the atom is electrically neutral and does not have an electrical charge.
- Positive charge (+) - If there are more protons than electrons, the atom is positively charged.
- Negative charge (-) - If there are more electrons than protons, the atom is negatively charged.

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

If there are too many or too few neutrons for a given number of protons, the resulting nucleus will have too much energy in it and will not be stable. The unstable atom will try to become stable by giving off excess energy in the form of particles or waves (radiation). These unstable atoms are also known as radioactive atoms.

5. Binding Energy

When a nucleus is assembled from the constituent parts (protons and neutrons) it is observed that the mass of the atom found in the environment is less than the calculated mass of the neutrons and protons. This difference in mass is the known as the mass defect or binding energy.

6. Radiation Basics

An element is a group of atoms having a specific number of protons. All atoms of the same element react about the same chemically. A nuclide is an atom with a specific number of protons and neutrons. There are about 300 naturally occurring nuclides. Of these, 264 are stable (not radioactive). There are more than 2100 man-made nuclides. All of them are radioactive. Many elements that are currently man-made were found naturally in the environment, such as Plutonium.

An isotope is one of a series of atoms of an element such as ^{3}H, which is an isotope of Hydrogen. All of the isotopes above the element of lead ($Z = 82$) are radioactive.

7. Radioactive Emissions

Most radioactive nuclides have too many protons or neutrons and are not stable. These nuclides emit or absorb one or more particles to correct and stabilize the atom. When this occurs, the nuclide is transformed into a different element. To stabilize the atom, the radioactive nuclei with either:

Convert a proton to a neutron:

One of the protons captures an electron and converts into a neutron. This is an electron capture (ec) process. The inter-most electron is absorbed into the nucleus and is accompanied by a characteristic x-ray emission as outer shell electrons fall into the vacated inner an orbit. The electron capture event cannot be detected, but the x-rays can be observed. The atom changes to a different element.

Positron decay ($\beta+$) is the release of a positive particle from the nucleus that is similar to an electron but positively charged. It is often referred to as antimatter. It is always accompanied by two characteristic gamma rays of 0.511 MeV. In the process as the Positron collides with a free electron (both will have the same mass) the mass of the two particles is converted into energy.

Convert a neutron to a proton

One of the neutrons ejects a specific amount of mass with a negative charge and is converted to a proton. This is referred to as Beta decay (β^-). This is a release of a negative particle (electron) from the nucleus and is accompanied by the emission of neutrinos. Neutrinos do not interact with matter, cannot be measured, by conventional means and pose no health risk. The atom changes to a different element.

Alpha decay

The nucleus ejects two protons and two neutrons (nucleus of a Helium atom). This is an alpha (α) decay. As the alpha particles losses its kinetic energy (energy of motion) it captures two free electrons and becomes ^{4}He. The remaining particle that emitted the alpha particle changes to a different element.

Neutron decay

The nucleus ejects one or more neutrons. In approximately eleven seconds the neutron will decay into a proton and capture an electron to become Hydrogen. The remaining particle will change to a different isotope. It does not change into a different element.

B. DEFINITIONS

1. Ionization

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 positive (+) charge. The positively charged atom and the negatively charged electron are called an ion pair. Ionization should not be confused with radiation. Ions (or ion pairs) can be the result of radiation exposure and allow the detection of radiation.

2. Ionizing Radiation

Energy (particles or rays) emitted from radioactive atoms can cause ionization, see figure A.1.2. The four basic types of ionizing radiation that are of primary concern in the nuclear industry are alpha particles, beta particles, gamma rays and neutron particles.

3. Isobars

Any nuclide that has the same atomic mass but differ in the number of neutrons or protons.

4. Isotones

Any nuclide that has the same number of neutrons but differ in the number of protons. They have the same atomic number but different atomic mass.

5. Isotope

Any nuclide that has the same number of protons but differ in the number of neutrons. They have the same atomic number but different atomic mass.

6. Non-ionizing Radiation

Radiation that doesn't have the amount of energy needed to ionize an atom is called "non-ionizing radiation," see figure 1.2. Examples of non-ionizing radiation are radar waves, microwaves and visible light.

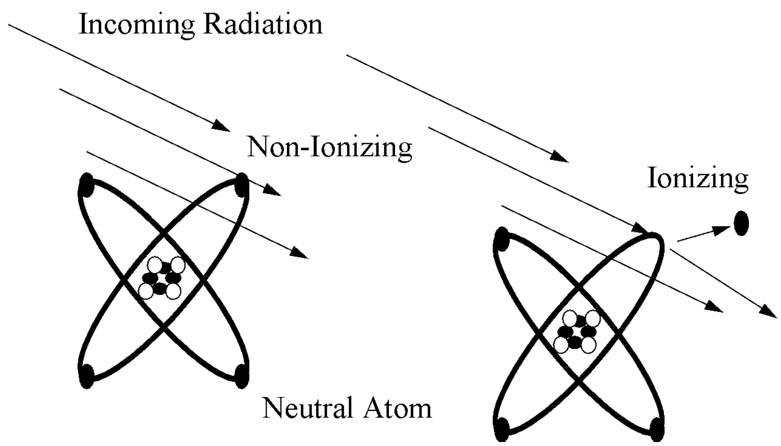


FIGURE 1.2 - IONIZING RADIATION VERSUS NON-IONIZING RADIATION

7. Nucleon

Refers to a nuclear particle, which can be either a neutron or a proton.

8. Radioactive material

It is defined as any material containing (unstable) atoms that emit radiation.

9. Radioactive contamination

It is any radioactive material in an unwanted location. There are certain places where radioactive material is beneficial. Radiation is a type of energy and contamination is a material. Therefore, exposure to radiation does not result in contamination of the worker.

10. Radioactivity

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

11. Radioactive decay

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

12. Radioactive half-life

Radioactive half-life is the time it takes for one half of the radioactive atoms present to decay. After seven half-lives the activity will be less than 1% of the original activity. The decay rate or activity, A, at any time, t, can be described mathematically:

$$A = A_o\ e^{-0693\ t/T_{1/2}}$$

A	= the activity after the elapsed time, t
A_o	= the original activity
t	= the elapsed time since the original activity
$T_{1/2}$	= the physical half-life of the nuclide
e	= exponential decay rate

Example: What is the remaining activity of ^{32}P after 7 days? The original activity was 12 mCi.

A_o	= 12 mCi
t	= 7 days
$T_{1/2}$	= 14 days (for ^{32}P)
e	= exponential decay rate

$$A = A_o\ e^{-0.693\ t/T_{1/2}} = \quad 12\ \text{mCi} \times e^{-0.693\ 7/14} \quad = \quad 8.49\ \text{mCi}$$

C. THE FOUR BASIC TYPES OF IONIZING RADIATION

The four basic types of ionizing radiation of concern in the nuclear industry are alpha particles, beta particles, gamma rays and neutron particles.

1. Alpha Particles

Physical characteristics

The alpha particle has a large mass and consists of two protons, two neutrons and no electrons see figure 1.3. It has a positive electric charge of plus two. It is a highly charged particle that is emitted from the nucleus of an atom. The positive charge causes the alpha particle (+) to strip electrons (-) from nearby atoms as it passes through the material, thus ionizing an atom.

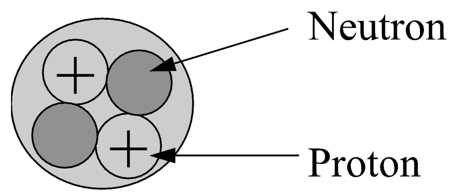


FIGURE 1.3 - ALPHA PARTICLE

- Range
  The alpha particle deposits a large amount of energy in a short distance of travel. This means that it deposits all of its energy in a short distance (High Linear Energy Transfer). This large energy deposit limits the penetrating ability of the alpha particle to a very short distance. This range in air is about one to two inches.

- Shielding
  Most alpha particles are stopped, by a few centimeters of air, a sheet of paper, or the dead layers of skin.

- Biological Hazard
  Alpha particles are not considered an external radiation hazard, because the dead layer of skin can easily stop them, see figure 1.4. Should an alpha emitter be inhaled or ingested, 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.

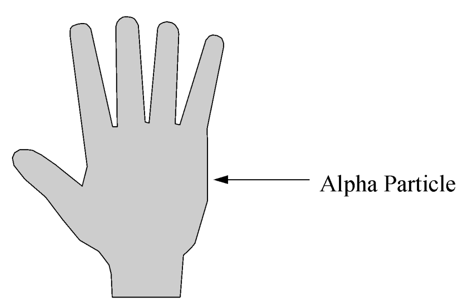


FIGURE 1.4 - PENETRATION OF ALPHA PARTICLES

2. Beta particles

Physical Characteristics

The beta particle has a small mass and is negatively charged. It is emitted from the nucleus of an atom as a neutron change into a proton in the nucleus and has an electrical charge of minus one. Beta radiation causes ionization by displacing electrons from their orbits. The beta particle is physically identical to an electron. Ionization occurs due to the repulsive force between the beta particle (-) and the electron (-), both of which have a charge of minus one.

- <u>Range</u>
  Because of its negative charge, the beta particle has a limited penetrating ability. Range in air is about 10 feet.

- <u>Shielding</u>
  Most beta particles are shielded by plastic, glass, metal foil, or safety glasses.

- <u>Biological Hazard</u>
  If ingested or inhaled, a beta emitter can be an internal hazard due to its short range. Externally, beta particles are potentially hazardous to the skin, see figure 1.5, and eyes.

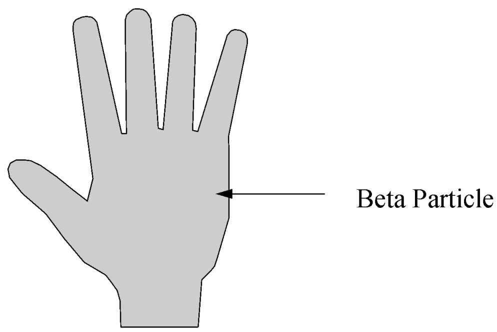


FIGURE 1.5 - PENETRATION OF BETA PARTICLES

Sometimes a beta particle with a positive charge is emitted. It is referred to as a Positron. A few isotopes, such as ^{11}C, ^{13}N, and ^{18}F, decay by positron emission. A positron, the anti-particle of a beta particle, is emitted by a proton-rich nucleus. It has the same mass as an electron, but carries a positive charge. During the decay event a proton converts to a neutron and a positive electron (or positron) that is ejected from the nucleus. The positron typically travels not more than a few millimeters before annihilating with a free electron to yield two 0.511 MeV photons perpendicular to angle of impact. All of the mass from the electrons is converted to electromagnetic energy.

3. Gamma Rays/X-Rays

<u>Physical Characteristics</u>

Gamma/x-ray radiation is an electromagnetic wave or photon and has no electrical charge or mass. Gamma rays are very similar to x-rays. The difference between gamma rays and x-rays is the place of origin. Gamma rays are typically more energetic than x-rays. Gamma/x-ray radiation can ionize as a result of direct interactions with orbital electrons. The energy of the gamma/x-ray radiation is transmitted directly to its target.

- <u>Range</u>
  Because gamma/x-ray radiation has no charge and no mass, they have a very high penetrating power, see figure 1.6. The range in air is very far compared to alpha and beta radiation. It will easily travel several hundred feet. The range depends upon the energy associated with the radiation. The greater the energy, the greater the range.

- <u>Shielding</u>
  Gamma/x-ray sources require shielding by very dense materials, such as concrete, lead or steel. Atoms with large numbers of protons (high Z) have large numbers of electrons. High Z elements make the best shields for gamma/x-ray radiation.

- <u>Biological Hazard</u>
  Gamma/x-ray radiation can result in radiation exposure to the whole body.

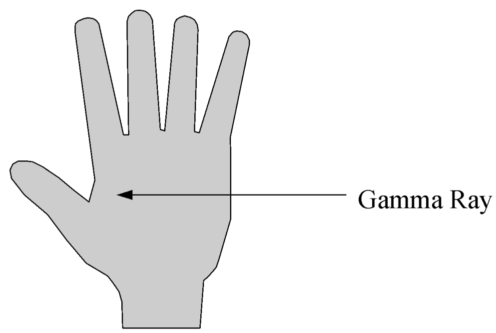


FIGURE 1.6 - GAMMA PENETRATION

4. Neutron particles

<u>Physical Characteristics</u>

Neutron particles are ejected from the nucleus of the atom. A neutron has no electrical charge. Due to their neutral charge, neutrons interact with matter either directly or indirectly.

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

A charged particle or other ionizing radiation may be emitted during these interactions that can cause ionization in human cells. This is called indirect ionization.

- <u>Range</u>
  Because of the lack of a charge, neutrons have a relatively high penetrating ability and are difficult to stop, see figure 1.7. Range in the air is very far. Like gamma rays, they can easily travel several hundred feet in air.

- <u>Shielding</u>
  Neutron radiation is best shielded by materials with large hydrogen content, such as water or boron. Boron is a good absorber of neutrons.

- Biological Hazard

  Neutrons are a whole-body hazard due to their high penetrating ability.

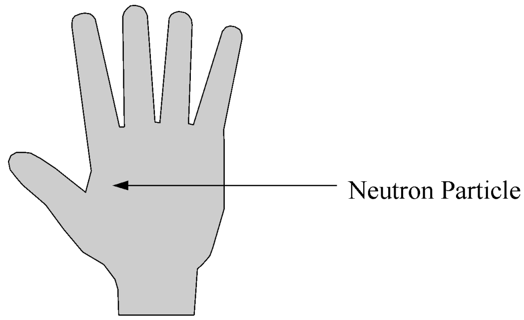


FIGURE 1.7 - NEUTRON PENETRATION

Other considerations for emission include that most beta emitters decay to an excited daughter state that releases excess energy from the nucleus as a gamma ray. Gamma rays are always preceded by charged particle decay, usually beta decay.

$^{137}Cs \rightarrow {}^{137m}Ba + {}^{0}\beta$- (1.176 MeV);

$^{137m}Ba \rightarrow {}^{137}Ba + {}^{0}\gamma$ (0.662 MeV)

5. Other Processes

The second decay is called an isomeric transition from the metastable state to the ground state. If a metastable daughter is sufficiently long-lived, it can be chemically separated from the parent.

When an excited metastable nucleus goes to the ground state by transferring its energy to a valence electron that is ejected, the process is called internal conversion.

Some proton-rich radionuclides decay by electron capture process. An orbiting electron, usually from the K shell, enters the nucleus and combines with a proton to yield a neutron. Its vacancy is filled by a cascading valence electron that releases its excess energy as a characteristic x-ray. The excess energy can cause the ejection of a valence electron, called an Auger electron.

A few very massive nuclei can decay by spontaneous fission. This is the process when the massive nuclei break apart into two or more elements with a tremendous release of (binding) energy.

D. UNITS OF MEASURE

1. Roentgen (R)

The Roentgen is a unit for measuring exposure of gamma or x-ray in air. It is defined only for the amount of energy deposited in air. It is a unit of measure only for gamma and x-ray. It does not relate biological effects of radiation to the human body. The International System of Units (SI) for Roentgens is Coulombs/kilogram (C/kg).

1 R (Roentgen) = 1000 milliroentgen (mR)

The Roentgen is the same in SI units and the English units.

2. Radiation Absorbed Dose (RAD)

The rad is a unit for measuring absorbed dose in any material from any type of radiation. Absorbed dose results from energy being deposited by the radiation per unit of mass. 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 human body. The SI unit for absorbed dose is measured by the gray, (Gy), which is equal to 1 joule of energy absorbed per kilogram.

1 rad = 1000 millirad (mrad)	1 milliGray = 0.001 Grays
1 gray = 100 rad	1 rad = 0.01 Grays

3. Roentgen Equivalent Man (REM)

A measure of the accumulation of radiation energy (dose) received over a period of time. It relates to the potential biological impact on human cells from radiation exposure. The rem is a unit for measuring dose equivalence. It is the most commonly used unit and pertains to man. The rem takes into account the energy absorbed (dose) and the biological effect on the body due to the different types of radiation. The SI unit for dose equivalence is the sievert, (Sv) which is equal to 1 biologically weighted joule per kg.

1 rem = 1000 millirem (mrem)	1 mSv = 0.1 rem = 100 mrem
1 Sv = 1000 milliSv = 100 rem	0.01 Sv = 1 rem

- Radiation Dose Rate
  Dose is the amount of radiation you receive. Radiation dose rate is the rate at which you receive the dose. For example:

Radiation dose rate (to humans) = dose/time; such as rem/hour or Sv/hour

4. Contamination/Radioactivity

- Contamination Units
  a. Disintegration per minute (dpm)
  b. Counts per minute (cpm)

Radioactivity is measured as the number of disintegrations radioactive material undergoes in a certain period of time. The US unit of activity is the curie (Ci). Most laboratories use milli or microcurie amounts.

One curie (unit of radioactivity) =

2,200,000,000,000 (2.2×10^{12}) disintegrations per minute (dpm)

OR

37,000,000,000 (3.7×10^{10}) disintegrations per second (dps)

The SI unit for activity is the Becquerel (Bq), 1 Bq equals 1 dps.

For the radioactivity in air and water the curie (Ci) or microcurie (mCi) is most often used in the US. One curie equals one million microcuries.

1 curie = 1,000,000 μCi = 3.7×10^{10} Bq

Section 2. Biological Effects

LEARNING OBJECTIVES:

IDENTIFY the average annual dose to the general population from natural background and man-made sources.
IDENTIFY the major sources of natural background and man-made radiation.
STATE the method by which radiation causes damage to cells.
IDENTIFY the possible effects of radiation on cells.
DEFINE the terms "acute dose" and "chronic dose".
LIST examples of a chronic radiation dose.
DEFINE the terms "somatic effect" and "heritable effect".
STATE the potential effects associated with prenatal radiation doses.
COMPARE the biological risks from chronic radiation doses to health risks workers are subjected to in industry and daily life.

INTRODUCTION

Whether the source of radiation is natural or man-made, whether it is a small dose of radiation or a large dose, there will be some biological effects. Small doses will produce biological effects; however, these effects may not be observable and possibly even provide a life lengthening effect. Humans have evolved in a radiation environment.

Of all existing environmental factors that are suspected to be a hazard to humans, we know more about the biological effects of ionizing radiation than any other. We have a large body of information available regarding exposures to humans as well as to animals.

There have been four significant events in recent history that exposed large groups of people to radiation. These events have allowed us to study the effects on human biology.

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

The second group is the more than 100,000 survivors of the atomic bombs dropped at Hiroshima and Nagasaki. These survivors received estimated doses in excess of 500 Sv (50,000 rem).

The third group consists of individuals who have been involved in radiation accidents, the most notable being the 1986 Chernobyl accident.

The fourth and largest group is comprised of radiation therapy patients who have undergone treatment for cancer.

A. SOURCES OF RADIATION

We live in a world that has always provided radiation exposures. As human beings, we have evolved in the presence of ionizing radiation that comes from the natural background radiation. The natural background is the radiation we receive primarily from the (1) cosmic, (2) terrestrial, (3) food, and (4) radon. The majority of us will be exposed to more ionizing radiation from natural background than from our employment.

The average annual radiation dose to a member of the general population in the US is about 360 millirem (3.6 mSv). This dose includes man-made radiation sources, mostly from medical procedures. It does not include occupational, intentional or accidental exposures.

1. Natural Sources

There are four primary sources of naturally occurring radiation exposures. The radiation emitted from these sources is identical to the radiation that results from the man-made sources.

a. Cosmic radiation

Cosmic radiation comes from solar (our sun) and galactic (deep outer space) sources and consists of positively charged particles as well as gamma radiation. At sea level, the average annual cosmic radiation dose is about 26 mrem (0.26 mSv). At higher elevations the amount of atmosphere shielding cosmic rays decreases and thus the dose increases. The total average annual dose to the general population from cosmic radiation is about 28 mrem (0.28 mSv).

b. Sources in earth's crust (terrestrial)

There are natural sources of radiation in the ground, rocks, building materials and drinking water. Some of the contributors to terrestrial sources are the natural radioactive elements such as radium, uranium and thorium. Many areas have elevated levels of terrestrial radiation due to increased concentrations of uranium or thorium in the soil. The total average annual dose to the general population from terrestrial radiation is 28 mrem (0.28 mSv).

c. Internal

Our food and water contain some trace amount of natural radioactive materials. These naturally occurring radioactive materials are deposited in our bodies and, as a result, cause an internal exposure to radiation. Some naturally occurring radioactive isotopes include Na-24, C-14, Ar-41 and K-40. Most of our internal exposure comes from K-40. Combined exposure from internal sources of natural background radiation account for a radiation dose of about 40 mrem (0.4 mSv) per year.

d. Radon

Radon comes from the radioactive decay of radium, which is naturally present in the soil. Because radon is a gas, it can travel through the soil and collect in basements or other areas of a home. Radon emits alpha radiation. Because alpha radiation cannot penetrate the dead layer of skin on your body, it presents a hazard only if taken into the body.

Radon and its decay products are present in the air. When inhaled it can cause a dose to the lung of approximately 2400 mrem (24 mSv) per year. This is equivalent to a whole-body dose of 200 mrem (2 mSv).

2. Man-made Radiation Sources

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

- Medical radiation (X-ray, Gamma radiation and Radio-isotope)
- Atmospheric testing of nuclear weapons
- Consumer products
- Industrial uses

a. Medical radiation sources

a. Medical Radiation

X-rays are identical to gamma rays; however, they originate at the electron cloud outside the nucleus. X-rays are an ionizing radiation hazard. A typical radiation dose from a chest x-ray is about 10 mrem (0.1 mSv). The total average annual dose to the general population from medical x-rays is 40 mrem (0.4 mSv).

Diagnosis and therapy

In addition to x rays, radioactive sources used in Nuclear Medicine, Radiation Oncology, Radiation Therapy and other specialties areas are used in medicine for diagnosis and therapy. The total average annual dose to the general population from these sources is 14 mrem (0.14 mSv).

b. Atmospheric testing of nuclear weapons

Another man-made source of radiation is residual fallout from atmospheric nuclear weapons testing in the 1950s and early 1960s. Atmospheric testing is now banned by most nations. The average annual dose from residual fallout is less than one mrem (0.01 mSv) a year.

c. Consumer products

Examples of consumer products that contribute to radiation exposures include TVs, older luminous dial watches and some smoke detectors. This dose is relatively small compared to other naturally occurring sources of radiation and averages 10 mrem (0.1 mSv) a year.

d. Industrial uses

Industrial uses of radiation include x-ray machines (radiography) used to test pipe welds and bore holes.

B. EFFECTS OF RADIATION ON CELLS

Each organ of the human body is made up of specialized cells. Ionizing radiation can potentially affect the normal operation of these cells.

1. Biological effects begin with the ionization of atoms

The method by which radiation causes damage to any material is by ionization of atoms in the material. Thus, the method by which radiation causes damage to human cells is by ionization of atoms in the cells. Atoms make up cells that make up the tissues of the body. These tissues make up the various organs of human body. Any potential radiation damage to the body begins with damage to atoms.

Although we tend to think of biological effects in terms of the effect of radiation on living cells, in actuality, ionizing radiation, by definition, interacts only with atoms by a process called ionization. Thus, all biological damage effects begin with consequence of radiation interactions with the atoms forming the cells. As a result, radiation effects on humans proceed from the lowest to the highest level as noted in the below list.

Effects on Cells and Organs

- Direct effects on cells: damage to DNA from ionization
- Indirect effects on cells: decomposition of water in the cell
- Cellular sensitivity to radiation
- Organ sensitivity to radiation
- Whole-body sensitivity to radiation

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

When ionizing radiation hits a cell, it may strike a vital part of the cell like the nucleus or a less vital part of the cell. This occurrence is similar to being struck by a bullet; it may strike a vital part such as the head or may strike a less vital part such as a toe.

Even though all subsequent biological effects can be traced back to the interaction of radiation with atoms, there are two mechanisms by which radiation ultimately affects cells. These two mechanisms are commonly called direct and indirect effects.

Direct effects on cells: damage to DNA from ionization

If radiation interacts with the atoms of the DNA molecule, or some other cellular component critical to the survival of the cell, it is referred to as direct effect. Such an interaction may affect the ability of the cell to reproduce and, thus survive. If enough atoms are affected such that the chromosomes do not replicate properly, or there is a significant alteration in the information carried by the DNA molecule, then the cell may be destroyed by "direct" interference with its life-sustaining system.

Indirect effects on cells: decomposition of water in the cell

If the cell is exposed to radiation, the probability of the radiation interacting with the DNA molecule is very small since these critical components make up such a small part of the cell. However, each cell, just as is the case for the human body, is mostly water. Therefore, there is a much higher probability of radiation interacting with the water that makes up most of the cell's volume.

When radiation interacts with water, it may break the bonds that hold the water molecule together, producing fragments such as hydrogen (H) and hydroxyls (OH). These fragments may recombine or may interact with other fragments or ions to form compounds, such as water that would harm the cell. However, they could combine to form toxic substances, such as hydrogen peroxide (H_2O_2) that can contribute to the destruction of the cell.

Cellular sensitivity to radiation

Not all living cells are equally sensitive to radiation. Those cells that are actively reproducing are more sensitive than those that are not, since dividing cells require that the DNA information be correct in order for the cell's offspring to survive. A direct interaction of the radiation could result in the death of such a cell, whereas a direct interaction with the DNA of a dormant cell would have less of an effect.

As a result, living cells can be classified according to their rate of reproduction, which also indicates their relative sensitivity to radiation. This means that different cell systems have different sensitivities.

- Lymphocytes (white blood cells) and cells that produce blood are constantly regenerating, and are therefore the most sensitive.
- Reproductive and gastrointestinal cells do not regenerate as quickly and are less sensitive.
- Nerve and muscle cells are the slowest to regenerate and are the least sensitive.

Cells, like those in the human body, have tremendous ability repair damage. As a result, not all radiation effects are irreversible. In many instances, the cells are able to completely repair any damage and function normally. Some studies indicate that low doses may stimulate the repair mechanism of the cells. This can result in an improvement of the health of the organism.

In some cases, the damage is severe enough that the cell dies. In other instances, the cell is damaged but is still able to reproduce. The daughter cells may be lacking some critical life-sustaining component and die. Finally, the cell may be affected in such a way that it does not die but is simply mutated. The mutated cell reproduces and thus perpetuates the mutation. This could be the beginning of a malignant tumor.

Organ sensitivity to radiation

The sensitivity of the various organs of the human body correlate with the relative sensitivity of the cells from where they were composed. For example, since the blood-forming cells are one of the sensitive cells and because of their rapid regeneration rate, the blood-forming organs are some of the most sensitive organs to radiation. Muscle and nerve cells are relatively insensitive to radiation, and therefore, so are the muscles and the brain.

The rate of the reproduction of the cells forming an organ system is not the only criterion determining overall sensitivity. The relative importance of the organ system to the well-being of the body is also important.

One example of a very sensitive cell system is a malignant tumor. The outer layer of cells reproduces rapidly, and also has a good supply of blood and oxygen. Cells are most sensitive when they are reproducing, and the presence of oxygen increases sensitivity to radiation. Anoxic cells (cells with insufficient oxygen) tend to be inactive such as the cells located in the interior of a tumor.

As the tumor is exposed to radiation, the outer layer of rapidly dividing cells is destroyed, causing it to “shrink” in size. If the tumor is given a massive dose to destroy it completely, the patient might die as well. Instead, the tumor is given a small dose each day, which gives the healthy tissue a chance to recover from any damage while gradually shrinking the highly sensitive tumor.

The developing embryo is also composed of rapidly dividing cells with a good blood supply and lots of oxygen. Although similar is sensitivity to a tumor, an embryo would suffer consequences of exposure to radiation that differ dramatically.

Whole-body sensitivity to radiation

Whole body sensitivity depends on the most sensitive organs that, in-turn, depends on the most sensitive cells. As noted previously, the most sensitive organs are the blood forming organs and the gastrointestinal system.

The biological effects on the whole body from exposure to radiation will depend upon several factors. Some of these are listed below. For example, a person, already susceptible to infection, who receives a large radiation dose may be affected by the radiation more than a healthy person.

- Total dose
- Type of cell
- Type of radiation
- Age of individual
- State of cell division
- Part of body exposed
- General state of health
- Tissue volume exposed
- Time interval over which dose is received

1. Cell sensitivity

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

Actively dividing cells (and non-specialized cells)

When a cell is in the process of dividing, it is less able to repair any damage. Therefore, cells in the body that are actively dividing are more sensitive to environmental factors such as ionizing radiation. Cells that rapidly divide include blood-forming cells, the cells that line our intestinal tract, hair follicles and cells that form sperm.

Less actively dividing (and more specialized cells)

Cells that divide at a less rapid pace or are more specialized (such as brain cells or muscle cells) and are not as sensitive to damage by ionizing radiation. During mitosis, cells are larger and become an easier target for the incoming radiation to hit.

3. Possible Effects of Radiation on Cells

When a cell is exposed by something in its environment, such as ionizing radiation, several things can happen. More information on cell biology is contained in Appendix B.

There may be no damage.

Cells repair the damage and operate normally.

The body of most cells is made up primarily of water. Therefore, when ionizing radiation hits a cell, it is most likely to interact with the water in the cell. Often the cell can repair this type of damage. Ionizing radiation can also hit the nucleus of the cell. The nucleus contains the vital parts of the cell such as chromosomes, which determines the cell function. When chromosomes replicate, they transfer their information to new cells. Although often more difficult, damage to chromosomes can also be repaired. In fact, the average human body repairs approximately 100,000 chromosome breaks per day.

Cells are damaged and operate abnormally.

The human cell is very resilient. In many cases it just repairs the damage and continues to function. But the damage might not be completely or even partially repairable. In that case, the cell may not be able to do its function, or it may die. It is possible that a chromosome in the cell nucleus could be damaged but not be repaired correctly. This is called a mutation or genetic effect. Genetic effects will be discussed when chronic radiation doses are considered.

Cells die as a result of damage.

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

Radiation effects on cell constituents

It takes about 3000 to 5000 rads (30 to 50 Grays) of absorbed dose to rupture the cell membrane. This is a major injury to the cell and allows the extracellular fluids to enter into the cell. It would allow leakage out of ions and nutrients that the cell brought inside. Membrane rupture may result in the death of a cell. This death would be compared to drowning. A large dose below 3000 rads (30 Grays) increases the permeability of the cell membrane and would allow leakage to occur.

Radiation effects on cytoplasm are negligible compared to observed effects on structures that are suspended within it. The first involve the mitochondria. It requires a few thousand rad to disrupt their function. This results in the immediate interruption of the cells food supply of ATP (adenosine triphosphate). The greater the dose received, the longer the repair time will be. If the stored food supply is not adequate to nourish the cell during repair, then the cell will die from starvation.

Another organelle within the cytoplasm that is affected by radiation is the lysosome. The lysosome will be ruptured at dose levels between 500 and 1000 rads (5 and 10 Grays). When this occurs, the enzymes are released within the cell and begin digesting structures of the cell. This cell death can be compared with suicide. At much larger doses the digestive enzymes are rendered inactive.

The most radiologically sensitive part of the cell is the nucleus. Because there is a wide band of sensitivity for cell nuclei, quantifying a dose range would be difficult. The major effect of radiation on the cell nucleus is the inhibition of DNA and RNA production. This means that the cell is unable to prepare for division. Before a cell divides it produces a complete duplicate set of chromosomes that carry all the information needed to reproduce the organism. Without DNA, duplicate chromosomes cannot be manufactured. If this process is delayed long enough, the cell dies and the death of the cell can be compared to death in childbirth. At lower doses DNA production is delayed only a short time. As the dose is increased, the delay period gets longer until death occurs.

Direct and indirect effects

A great many agents can cause injuries to the human cell. When such injury occurs, the effects are the same regardless of the agent that caused the damage. Ionizing radiation produces damage to cells, but in a mostly nonspecific way; that is, other physical and chemical substances cause the same effects because the body responds the same to certain cell damage regardless of the cause.

Radiation passing through living cells will directly ionize or excite atoms and molecules in the cell structure. These changes affect the forces that bind the atoms together into molecules. If the molecule breaks up (dissociates), some of the parts will be charged. These fragments are called free radicals and ions, and are not chemically stable. Free radicals are electrically neutral structures with one unpaired electron. Because the cell has higher water content, the most important free radicals are those formed from water molecules. The free radicals are very reactive chemically, and when combining can produce hydrogen peroxide (H_2O_2), that is a chemical poison. Further effects are produced when the radicals and ions interact with other cell material. In this way, damage is caused in a direct and indirect manner. The role that each type of action plays in the total damage to the cell is still an unsolved problem. Of the damage that is done, the effects are greatest in the nucleus of the cell, but injury to the cytoplasm can also cause serious effects in the cell.

The total effect on cell processes is a function of the dose of radiation. The cell processes will be affected in varying degrees up to the ultimate result – cell death. Some damage to the cell may be repaired. This can be accomplished by action of the cell itself, or by replacement of badly injured cells in a given tissue through mitosis of healthy cells. If the extent of the damage to an organ is quite large, the organ may not be able to repair itself. Damaged cells may show confused growth but eventually be unable to divide. Or the cells may begin to exhibit uncontrolled growth. Although many factors are important in assessing the total damage, it seems likely that most cell functions and structures are somewhat impaired by radiation.

C. ACUTE AND CHRONIC RADIATION DOSE

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

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

Lethal dose

Not only do various organisms vary in their sensitivity to radiation, but individuals of the same species also react differently. Because of this biological variability, the dose that is lethal to 50 percent of the individuals exposed is used. The concept used is LD 50/30. LD 50/30 is defined as the dose of radiation expected to cause death (Lethal Dose) to 50 percent of those exposed in 30 days without medical treatment.

1. Acute radiation doses

An acute effect is a physical reaction due to massive cell damage. This damage may be caused by a large radiation dose received in a short period of time, an acute dose. Acute effects are classified as effects that occur within 1-2 months of the exposure. The body can't repair or replace cells fast enough from an acute dose, and physical effects such as reduced blood count and hair loss may occur. Slight blood changes may be seen at acute doses of 10,000-25,000 mrem (100-250 mSv) but an individual should not otherwise be affected.

2. Radiation sickness

At acute doses greater than 100,000 mrem (1000 mSv or 1 Sv) about half of the population will experience nausea (due to damage of the intestinal lining). Radiation therapy patients often receive doses in this range and above, although dose to the region of a tumor is many times higher than this.

If the acute dose to the whole body is very large (500,000 mrem (5,000 mSv) or larger) it may cause so much damage that the body cannot recover. Thirty firefighters at Chernobyl received acute doses in excess of 800,000 mrem (8000 mSv). These individuals succumbed to the effects of the burns they received, compounded by their radiation exposure.

Radiation sickness is often referred to as radiation syndrome. However, a syndrome is a combination of symptoms resulting from a single cause. There are three syndromes from acute doses of radiation.

- Hematopoietic
- Gastrointestinal
- Central nervous system

Large acute whole-body exposures in man may result in one of three radiation syndromes. At the lowest doses sufficient to produce one of these syndromes (200-1000 rads or 2-10 Gy) the primary affected tissue is the hematopoietic system. At higher doses (1000-5000 rads or 10-50 Gy) the gastrointestinal tract is the critical tissue, although the hematopoietic system is also greatly affected. Above 5000 rads (50 Gy) we say that the dominant effects involve the central nervous system even though the hematopoietic system and gastrointestinal tract have been effectively destroyed by such a dose. Each syndrome can be considered to progress through the following four states:

- Prodromal (initial)
- Latent
- Period of illness
- Recovery or death

Prodromal stage

This is the first set of symptoms that occurs following a sufficiently large acute dose. The symptoms may include nausea, vomiting and diarrhea as well as anorexia (loss of appetite) and fatigue. The actual causes of the prodromal symptoms are unknown. To some degree, the time of onset of these symptoms are indicative of the magnitude of the dose. However, the appearance of these symptoms, especially nausea and vomiting, can also be induced psychologically.

A clinically observable biological effect that occurs days to months after an acute radiation dose is a deterministic effect. Examples are skin reddening or swelling, epilation, or hematologic depression. Deterministic effects require a dose that is greater than a threshold, typically greater than tens or hundreds of rads.

Latent phase

This is an asymptomatic period between the prodromal stage and the onset of symptoms of later stages. The higher the dose the shorter the latent phase. At sufficiently high does the latent phases effectively disappears.

Illness

Many of the characteristics of the prodromal stage reoccur along with a variety of additional symptoms such as ulcerations about the mouth, fever, etc.

Recovery or death

In the past (25-30 years ago) an acute dose above 1000 rads or 10 Gy, death was probably certain, even with the best of medical care. Current medical advances have pushed the recovery to doses around 2000 rads or 20 Gy. It is generally believed that without medical attention: death is certain above 600 rads or 6 Gy, About 50 percent of the exposed population would die from 400 rads or 4 Gy ($LD_{50/30}$) and about 5 percent would die from 200 rads or 2 Gy. If the patient survives six weeks, recovery is assured although delayed (late) effects are still possible.

3. After an acute dose to the whole body

After an acute dose, new cells will replace the damaged cells, and the body will repair itself over the course of several of months. Only in those extreme accidents such as Chernobyl, would the dose be so high as to make recovery unlikely.

4. Acute doses to only part of the body

It is possible in that radiation exposure may be only to a limited part of the body such as the hand. There have been accidents, particularly with x-ray machines, when individuals have exposed their fingers to part of the x-ray beam. In some of these cases individuals have received doses of <u>millions</u> of mrem to their hand causing loss of one or more fingers. It is important for those who work with x-ray equipment or similar equipment to be trained in the safe use of this equipment.

5. Probability of an acute dose

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

6. Chronic radiation doses

A chronic radiation dose is typically a small amount of radiation received over a long period of time. A typical example of a chronic dose is the daily dose we received from natural background or the dose received from occupational exposure.

7. Chronic dose versus acute dose

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. It is only when the dose of radiation is so high or is received very rapidly that the cellular repair mechanisms are overwhelmed, and the cell dies before repair can occur. A chronic dose of radiation does not result in physical changes to the body such as is seen with acute doses. Because of cell repair, even sophisticated analysis of the blood, do not reveal any biological effects.

Radiation dose can increase the chance of contracting a cancer. This is an example of stochastic effect. The increase in chance is assumed to be proportional to the dose, and it is assumed there is no minimum threshold. Scientist disagree on whether this conservative linear non-threshold model is the best mathematical representation of the risk of cancer induction.

8. Genetic effects

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

9. Somatic Effects

Chronic radiation exposure effects involve a low dose over a relatively long period of time (weeks to years). The effects, if any occur, do not manifest themselves until many years after the exposure. Damage to some genetic material in the cell could eventually cause that cell to become a cancer cell. This is an example of a somatic effect. The probability of this is very low at occupational doses.

10. Heritable effects

A heritable effect is a genetic effect that is inherited or passed on to offspring. Although, the individual has experienced damage to some genetic material in the cell that doesn't directly affect his/her body, it will be passed on to future generations. Although heritable effects from radiation have been observed in studies of plants and animals, they have, so far, never been observed in humans. Studies have followed the 77,000 descendants of the survivors of Hiroshima and Nagasaki, all of whom were conceived after the atomic bombs.

The Law of Bergonie and Tribondeau indicate that the radiosensitivity of tissue is directly proportional to its reproductive capacity and inversely proportional to the degree of differentiation. It follows that children could be expected to be more radiosensitive than adults, fetuses more radiosensitive than children, and embryos even more radiosensitive.

11. Factors affecting biological damage due to exposure to radiation:

Total dose – In general, the greater the dose, the greater the biological effects are.

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

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

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

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

Individual sensitivity - Some individuals are more sensitive to environmental factors such as ionizing radiation. The developing embryo/fetus is the most sensitive, and children are more sensitive than adults. In general, the human body becomes relatively less sensitive to ionizing radiation with increasing age. The exception is that elderly people are more sensitive than middle-aged adults due to an inability to repair damage as quickly (less efficient cell repair mechanisms).

D. PRENATAL RADIATION EXPOSURE

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

1. Sensitivity of the unborn

Embryo/fetal cells are rapidly dividing. This makes them sensitive to any environmental factors such as ionizing radiation.

2. Potential effects associated with prenatal exposures

Many chemical and physical (environmental factors) are suspected or known to cause damage to an unborn child, especially early in the pregnancy. Alcohol consumption, exposure to lead, heat from hot tubs is only a few that have been publicized lately. Some children who were exposed while in the womb to the radiation from the atomic bomb were born with low birth weights and mental retardation. It has been suggested but is not proven that exposures to the unborn may also increase the chance of childhood cancer. Only when doses exceed 15,000 mrem or 150 Gy is there a significant increase in risk.

In an effort to be prudent, limits are established to protect the embryo/fetus from any potential effects that may occur from a significant amount of exposure to radiation. This exposure may be the result of exposure to external sources of radiation or internal sources of radioactive material. At present occupation dose limits, the actual risk to the embryo/fetus is negligible when compared to normal risk of pregnancy.

E. RISKS IN PERSPECTIVE

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

1. Risk from exposures to ionizing radiation

We do not know what the risks are at low levels of radiation exposure. No increases in cancer have been observed in individuals exposed to ionizing radiation at occupational levels, but the possibility of cancer induction cannot be dismissed because an increase in cancers has not been observed. Risk calculations have been derived from individuals who have been exposed to high levels of radiation.

2. Comparison of risks

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

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

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

Table 2.1 compares the estimated days of life expectancy lost as a result of exposure to radiation and other health risks. Those estimates indicate that the health risks from occupational radiation exposure are smaller than the risks associated with readily accepted normal day-to-day activities.

Table 2.2 addresses the estimated days of life expectancy lost as a result of exposure to radiation and common industrial accidents at radiation-related facilities and compare these numbers to days lost as a result of fatal work-related accidents in other occupations.

Because there may be some small risk from exposures to ionizing radiation, public policy is to practice keeping your exposures As Low As Reasonably Achievable (ALARA).

Table 2.1

Average Estimated Days Lost Due to Daily Activities

Health Risk	Average Estimated Days Lost
Unmarried Male	3500
Cigarette Smoking	2250
Unmarried Female	1600
Coal Miner	1100
25% Overweight	777
Alcohol (US Average)	365
Construction Worker	227
Driving a Motor Vehicle	207
100 mrem (1mSv) /year for 70 years	10
Coffee	6

Table 2.2

Average Estimated Days Lost in Other Occupations

Industry	Average Estimated Days Lost
Mining/Quarrying	328
Construction	302
Agriculture	277
Radiation Dose of 5,000 mrem (50 mSv) /yr for 50 years (Nuclear Industry)	250
Transportation/Utilities	164
All Industry	74
Government	55
Service	47
Manufacturing	43
Trade	30

Radiation Accidents (deaths from Exposure)	<1

Section 3. Radiation Limits

LEARNING OBJECTIVES:

STATE the purposes of the facility administrative control levels.
IDENTIFY the radiation dose limits, administrative control level and facility administrative control levels.
STATE the site policy concerning prenatal radiation exposure.
IDENTIFY the employee's responsibility concerning radiation dose limits and administrative control levels.
DESCRIBE the action a worker should take if he or she suspects that dose limits or administrative control levels are being approached or exceeded.

INTRODUCTION

Scientist had long known that exposure to radiation can have harmful effects on humans. Recent events such as Chernobyl have permitted refinement of our knowledge of the health effects of radiation. All radiation possesses energy. Biological absorption of radiation is that process of transferring the energy to atoms of tissue through which the radiation is passing. When radiation is absorbed into the living cells, the energy from the radiation is transferred to the atoms of the cell causing ionization (an electrical imbalance) that may be harmful.

Too much radiation exposure is harmful. The degree of radiation injury depends on the amount of radiation received and the portion of the body exposed to radiation. In general, the higher the amount received, the greater the effects.

Intensity and duration of radiation exposure are factors affecting whether or not cells will repair damage or become overwhelmed, resulting in either cell death or retain the damage and cause problems years later.

In order to minimize the potential risks of biological effects associated with radiation, dose limits and administrative control levels have been established. Regulations have been based on the information from large doses in excess of background. An extrapolation was made of the large doses (acute doses) down to zero doses with the assumption that any dose is harmful. The assumption to zero does not appear to be supported by the observation of biological effects at low doses. See Table 3.1 below.

A. DOSE LIMITS AND FACILITY ADMINISTRATIVE CONTROL LEVELS

The regulatory radiation dose limits are established for occupational workers based on guidance from the Environmental Protection Agency (EPA), the National Council on Radiation Protection and Measurements (NCRP), and the International Commission on Radiological Protection (ICRP).

Many facilities establish administrative control levels for radiation workers that are more conservative than the regulatory limits. This is to ensure that regulatory limits and control levels are not exceeded and to help reduce individual and total worker population radiation dose (collective dose).

The regulatory dose limits and administrative control levels are as follows:

1. Whole body

Definition: The "whole body" extends from the top of the head down to a little below the knee. It also excludes the area just below the elbows. The "whole body" is the location of most of the blood-producing and vital organs.

Just as there are limits for external exposure to radiation, there are limits for internal exposure to radiation. Internal exposure is a result of radioactive material being inhaled, ingested, and absorbed through the skin or a wound. Limits are based on the sum of internal and external exposure.

The regulatory radiation dose limit during routine conditions is 5 rem/year (0.05 Sv). Many facilities, such as Department Of Energy, establish administrative control levels during routine conditions at 2 rem/year (0.02 Sv).

Table 3.1
The Biological Effects of Acute Radiation Exposure

(Assuming whole body exposures)

Rem (Sv)	Effects
0 – 50 (0 – 0.5)	No obvious effect, except possible minor blood changes.
80 – 120 (0.8 – 1.2)	Vomiting and nausea for about 1 day in about 1 to 10 percent of exposed individuals. Fatigue, but no serious disability.
130 – 170 (1.3 – 1.7)	Vomiting and nausea within 24 – 48 hours, followed by other symptoms of radiation sickness in about 25 percent of the exposed individuals. No deaths anticipated if treatment is instituted.
180 – 220 (1.8 – 2.2)	Vomiting and nausea within 24 hours, followed by other symptoms of radiation sickness in about 50 percent of the exposed individuals. Near 20 percent deaths if untreated.
270 – 325 (2.7 – 3.25)	Vomiting and nausea in all of the exposed individuals on the first day, followed by other symptoms of radiation sickness. Up to 50 percent deaths within 60 days if untreated. Survivors convalesce for about 6 months.

400 – 500 (4 – 5)	Vomiting and nausea in all of the exposed individuals on the first day, followed by other symptoms of radiation sickness. Greater than 50 percent among untreated patients within 2 months. Survivors convalesce for about 6 months.
550 – 750 (5.5 – 7.5)	Vomiting and nausea in nearly all of the exposed individuals within 4 hours of exposure, followed by other symptoms of radiation sickness. About 100 percent deaths in the untreated population in about two weeks.
1000 (10)	Vomiting and nausea in all exposed individuals within 1 to 2 hours. Probably no survivors among untreated patients.
5000 (50)	Incapacitation almost immediately. All exposed individuals die, mostly within 48 hours.

2. Extremities

Definition: Extremities include the hands and arms below the elbow and the feet and legs below the knees.

This area is not as sensitive to radiation as the organs of the whole body.

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

The regulatory radiation dose limit for extremities during routine conditions is 50 rem/year (0.5 Sv/year).

3. Skin and other organs

The regulatory radiation dose limit for skin and other organs during routine conditions is 50 rem/year (0.5 Sv/year).

4. Lens of the eye

The regulatory radiation dose limit for lens of the eye during routine conditions is 15 rem/year (0.15 Sv/year).

5. Declared pregnant worker (embryo/fetus)

General policy

A female radiation worker is encouraged to voluntarily notify her supervisor, in writing, when she is pregnant. The employer must provide the option of a mutually agreeable assignment of work tasks, with no loss of pay or promotional opportunity, such that further occupational radiation exposure is unlikely.

Regulatory limit

For a declared pregnant worker who chooses to continue working as a radiation worker, the following radiation dose limit will apply. The dose limit for the embryo/fetus (during entire gestation period) is 500 mrem (5 Sv). Efforts should be made to avoid exceeding 50 mrem/month (0.5 mSv/month) to the pregnant worker. If the dose to the embryo/fetus is determined to have already exceeded 500 mrem (5 Sv) when a worker notifies her employer of her pregnancy, the worker shall not be assigned to tasks where additional occupational radiation exposure is likely during the remainder of the pregnancy.

The declaration may be revoked, in writing, at any time by the declared pregnant worker.

6. Visitors and public

The regulatory radiation dose limit for visitors and the public is 0.100 rem/year (0.001 Sv).

7. Dose limits for workers performing emergency services

Workers who may incur increased levels of exposure under emergency conditions may include those employed in law enforcement, firefighting, traffic control, health services, etc. Guidance on dose limits for workers performing emergency services is summarized in Table 3.2 below. These limits apply to doses incurred over the duration of an emergency. Doses received must be deducted from the annual and lifetime limits.

Table 3.2

Worker Limits During Emergencies

(Whole body exposures are assumed)

Dose Limit Rem (Sv)	**Activity**	**Condition**
5 (0.05)	*All*	
10 (0.1)	Protecting valuable property	Lower dose not practicable
25 (0.25)	Lifesaving or protection of large populations	Lower dose not practicable
>25 (0.25)	Lifesaving or protection of large populations	Only on a voluntary basis to persons fully aware of the risks involved

B. WORKER RESPONSIBILITIES REGARDING DOSE LIMITS/CONTROL LEVELS

It is each employee's responsibility to comply with regulatory dose limits/control level and Facility administrative control levels.

Workers who suspect that dose limits or administrative control levels are being approached or exceeded, you should notify their supervisor immediately.

Section 4. ALARA Program

LEARNING OBJECTIVES:

STATE the ALARA concept.
STATE the DOE/Site management policy for the ALARA program.
IDENTIFY the responsibilities of management, Radiation Safety Organization and the radiation worker in the ALARA Program.
IDENTIFY the basic protective measures of time, distance and shielding.
IDENTIFY methods for reducing external and internal radiation dose.
STATE the pathways through which radioactive material can enter the body.
IDENTIFY methods a radiation worker can use to minimize radioactive waste.

INTRODUCTION

This section is designed to inform the student of the concept of ALARA (As Low As Reasonably Achievable). Methods for reducing both external and internal doses from radiation and radioactive material are also discussed.

Even though there are dose limits and administrative control levels, it is preferable to keep radiation dose well below these. Employees should always try to maintain their radiation dose As Low As Reasonably Achievable (ALARA).

A. ALARA PROGRAM

1. ALARA Concept

ALARA stands for <u>A</u>s <u>L</u>ow <u>A</u>s <u>R</u>easonably <u>A</u>chievable.

This concept includes reducing both internal and external exposure to ionizing radiation. The ALARA concept is an integral part of all site activities that involve the use of radioactive materials and other ionizing radiation sources. The implementation of the ALARA concept is the responsibility of all employees.

2. Management Policy

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

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

B. RESPONSIBILITIES FOR THE ALARA PROGRAM

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

1. Management

Management is responsible for establishing the ALARA program at the site. It is also responsible to ensure that a management structure is in place to implement such a program, and that the worker follows the program. Management is responsible to ensure that the program meets regulatory standards, guidelines, and regulations

2. Radiation Safety Organization

Not only is the Radiation Safety Organization responsible for implementing the ALARA program at the Site, it is also responsible for implementing the requirements for the entire Radiation Safety program. These requirements are established by the facility license and regulations.

Radiation Safety Technicians (Health Physics Technicians) provide an interface point for the worker to obtain the most current radiological conditions in an area. They provide assistance when trying to interpret protective requirements or radiological information concerning a work assignment, and they address radiological questions/concerns.

3. Radiation workers

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

4. Radiation Intensity

In order to use the basic methods for controlling exposure, the worker must be able to determine the intensity of the radiation field. The "rule-of-thumb" method to determine the radiation field intensity for simple sources of radioactive material is the "curie/meter/rem" rule.

1 Ci @ 1 meter = 1 R/hr (assuming gamma radiation in air)

To determine the gamma radiation field intensity for a radioactive point source.

$$I_{1ft} = 6CEN \quad \text{or} \quad I = 6CEN/r^2$$

$$I_{1m} = 0.5CEN \quad \text{or} \quad I = 0.5CEN/r^2$$

where:

I_{1ft}	=	exposure rate in r/hr at 1 ft.
I_{1m}	=	exposure rate in r/hr at 1 m.
C	=	activity in Ci (or $3.7\text{x}10^{10}$ Bq)
E	=	the gamma energy in MeV

N	=	the number of gammas per disintegration
r	=	feet or meters (watch units)

These equations are accurate to within ± 20 percent for gamma energies between 50 keV and 3 MeV.

Example: Determine the exposure rate at 1 foot for a 1Curie point source of ^{137}Cs that emits a 662 keV (0.662 MeV) gamma in 85 percent of its disintegrations.

Using equation $I_{1ft} = 6CEN$

I_{1ft} = 6(1 Ci)(0.662 MeV)(0.85 number of gammas per disintegration) = 3.38 R/hr

C. EXTERNAL RADIATION DOSE REDUCTION

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. Basic protective measures used to reduce external exposure include minimizing time in a field of radiation, maximizing the distance from a source of radiation and using shielding whenever possible. Even if the doses being received are below the regulatory limit, the management must continue to follow ALARA to reduce doses further.

1. Methods for minimizing time

Reducing the amount of time in a field of radiation will lower the dose received by the workers.

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

b. Have all necessary tools before entering the area.

c. Use mock ups and practice runs that duplicate work conditions.

d. Take the most direct route to the job site.

e. Never loiter in an area controlled for radiological purposes.

f. Work efficiently but swiftly.

g. Do the job right the first time.

h. Perform work outside the area as much as possible or, when practical, remove parts or components to areas with lower dose rates to perform work.

In some cases, such as synthesis operations, the Radiation Safety personnel may limit the amount of time a worker may stay in an area. This is known as a “stay time”. Once a stay time has been assigned, do not exceed this time. The exposure rate is inversely proportional to the square of the distance from the source.

The exposure received by personnel will increase as the time spent in the radiation field increases. The exposure received is equal to the radiation field intensity times the exposure time.

$X = (R/t)\ T$ where: X = exposure and R/t = exposure rate

Example: A worker performing maintenance in a location where the gamma exposure field is 75 mR/hr will require 2 hours to complete the task. What will his total exposure be for the job? SI units can be substituted directly.

Using the equation X = (R/t) T

X = (75 mR/hour) 2 hours = 150 mR

Table 4.1 below provides a guide to acceptable exposure times based on the radiation levels present and the desired maximum dose. To give an example, if you had a reading of 100 R/hr (rem/hr) you would be able to stay in the area for a maximum of 15 minutes without exceeding the exposure limits allowed. If you had 50 R/hr you could stay for 30 minutes. If the reading was only 2 R/hr you could stay for as long as 12,500 hours.

Table 4.1

Time to Receive Maximum Whole Body Dose

Dose Rate	500 mrem (5 Sv)	5 rem (0.05 Sv)	25 rem (0.25 Sv)
2 mR/hr	250 hours	2500 hours	12500 hours
10 mR/hr	50 hours	500 hours	2500 hours
25 mR/hr	20 hours	200 hours	1000 hours
50 mR/hr	10 hours	100 hours	500 hours
0.5 R/hr	1 hour	10 hours	50 hours
1.0 R/hr	30 minutes	5 hours	25 hours
50 R/hr	36 seconds	6 minutes	30 minutes
100 R/hr	18 seconds	3 minutes	15 minutes

2. Methods for maintaining distance from sources of radiation

a. Stay as far away as possible from the source of radiation.

b. For point sources, the dose rate follows the inverse square law.

$$\text{Dose} = 1/\text{Distance}^2$$

If the distance is doubled, the dose rate falls to 1/4 of the original dose rate. If the distance is tripled, the dose rate falls to 1/9 of the original dose rate.

c. Be familiar with radiological conditions in the area.

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

e. Use remote handling devices when possible.

The intensity of the radiation field decreases as the distance from the source increases. See figure 4.1 below. Increasing the distance will reduce the amount of exposure to the individual. In many cases increasing the distance from the source is more effective than decreasing the time spent in the radiation field. The exposure rate is inversely proportional to the square of the distance from the source.

$$(I_2)\ (d_2)^2 = (I_1)\ (d_1)^2$$

where:

I_1 = exposure rate at distance (d_1)

I_2 = exposure rate at distance (d_2)

d_1 = first distance from the source

d_2 = second distance from the source

An algebraic rearrangement of the equation yields:

$$(I_2) = I_1\ ((d_1)^2 / (d_2)^2)$$

Example: A 1 Curie point source of ^{137}Cs has a gamma exposure rate of 3.38 R/hr at 1 foot. What would the exposure rate be at 3 feet?

$$(I_2) = (3.38\ \text{R/hr})\ (1^2 / 3^2) \quad = \quad 0.376\ \text{R/hr or } 337\ \text{mR/hr}$$

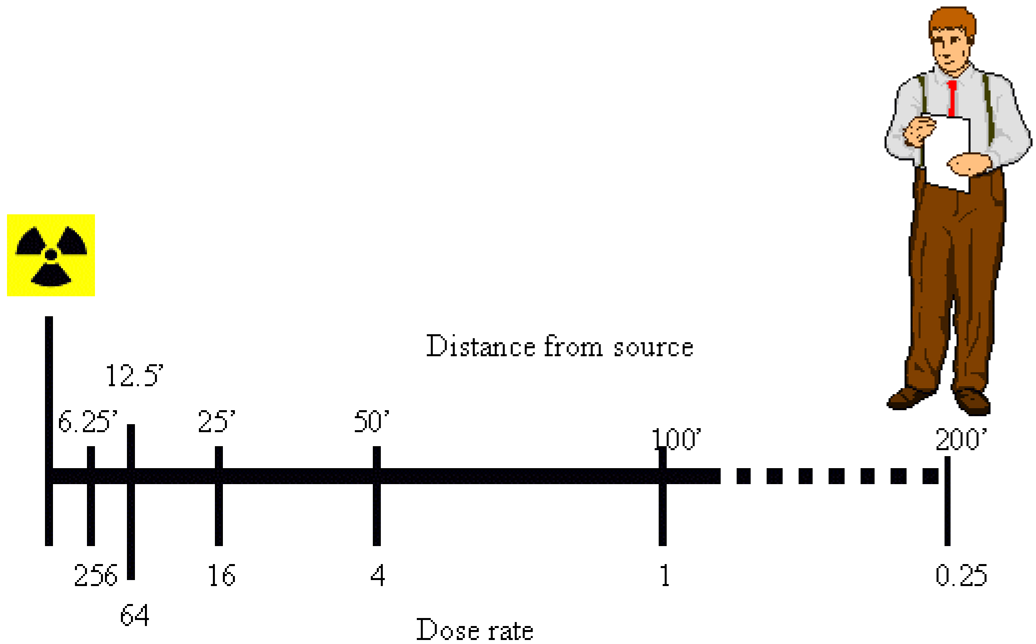


FIGURE 4.1 RADIATION DECREASES AS THE DISTANCE INCREASES

3. 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. See Figure 4.2 below.

a. Take advantage of permanent shielding such as non-radiological equipment/structures.

b. Use shielded containers when available.

c. Wear safety glasses/goggles to protect the eyes from beta radiation, when applicable.

   Temporary shielding (e.g. lead or concrete blocks) is often installed, and should be installed according to procedures established. Once temporary shielding is installed, it should not be removed without a thorough survey or proper authorization.

d. It should be remembered that the placement of shielding could actually increase the total dose (e.g., man-hours involved in placement, Bremsstrahlung, etc.).

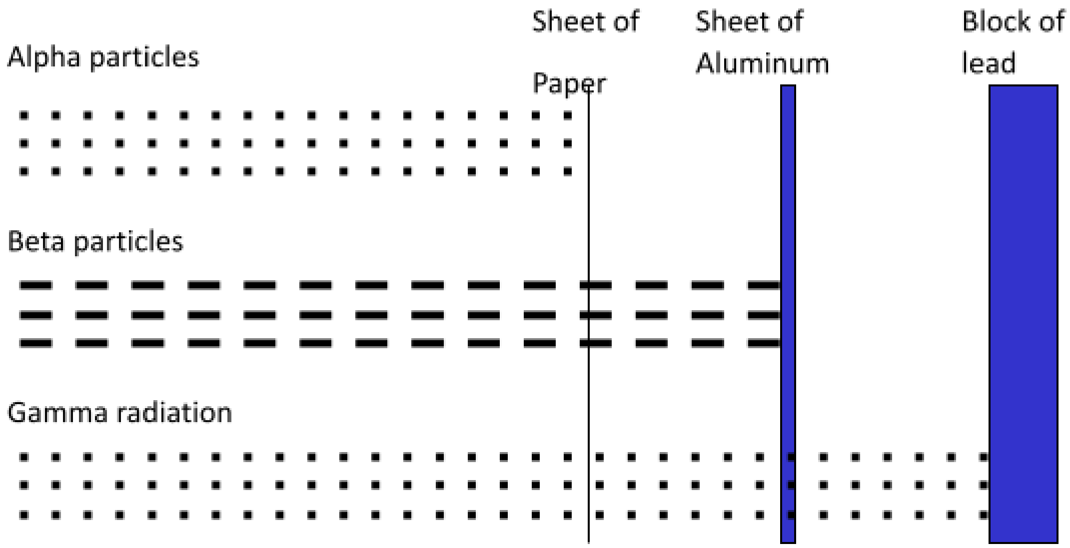


FIGURE 4.2 STOPPING POWER OF DIFFERENT SHIELDING MATERIALS

The determination of shielding is more complicated than that used for measuring the distance from a point source. The simplest method for determining the effectiveness of shielding material is using the concepts of half-value layers (HVL) and tenth-value layers (TVL).

One HVL is defined as the amount of shielding material required to reduce the radiation intensity to one-half of the unshielded value.

$HVL = \ln 2/\mu = 0.693/\mu$ Where μ is the mass of the shielding material.

One TVL is defined as the amount of shielding material required to reduce the radiation intensity to one-tenth of the unshielded value.

$TVL = \ln 10/\mu = \ln 2/\ln 10\ (HVL) = 3.3$

Note: One TVL is equivalent to 3.3 times the HVL.

Both of these concepts are dependent on the energy of the photon radiation and a chart can be constructed to show the HVL and TVL values for photon energies. See Table 4.2 below.

Table 4.2

Half-Value Layers

Photon energy (keV)	**Lead (11.35 g/cm3)**	**Iron (7.86 g/cm3)**	**Concrete (2.4 g/cm3)**	**Water (1.0 g/cm3)**
500	0.38	1.0	3.3	7.2
1000	0.86	1.5	4.5	9.8
1500	1.2	1.8	5.6	12.0
2000	1.3	2.1	6.4	14.0
3000	1.5	2.4	7.9	17.5

The basic approach to photon shielding is to determine the existing exposure rate, decide on the desired exposure rate after shielding and then calculate how many HVL will be needed. The basic equation for using the HVL concept is:

$$I = I_o \, (1/2)^n$$

Where: I = shielded exposure rate
Io = unshielded exposure rate
N = HVL = shield thickness (cm) / HVL (cm)

Note: For TVL, substitute a 10 for the 2 in the equation.

Example: Calculate the shielded exposure from a 250 mR/hr ^{137}Cs source with 5 cm of lead shielding. The HVL for ^{137}Cs and lead is 0.65 cm.

$$N = \# \text{ of HVL} = 5 \text{ cm} / 0.65 = 7.7 \text{ HVL}$$

$$I = 250 \text{ mr/hr } (1/2)^{7.7}$$

$$I = 2.4 \text{ mR/hr}$$

4. Source Reduction

By reducing the source, the exposure rate is reduced in proportion to the source strength. Many sealed sources do not allow this option. However, if more than one source is being used, and only one is needed, remove the unneeded sources.

D. INTERNAL RADIATION DOSE REDUCTION

Internal exposure is a result of radioactive material being taken into the body. Radioactive material can enter the body through one or more of the following pathways; (1) inhalation, (2) ingestion, (3) absorption through the skin, and (4) injection. See Figure 4.3 below. Preventive measures are designed to do one of two things: minimize the amount of radioactive materials present that is available to enter the body, or block the pathway from the source of radioactive materials into the body.

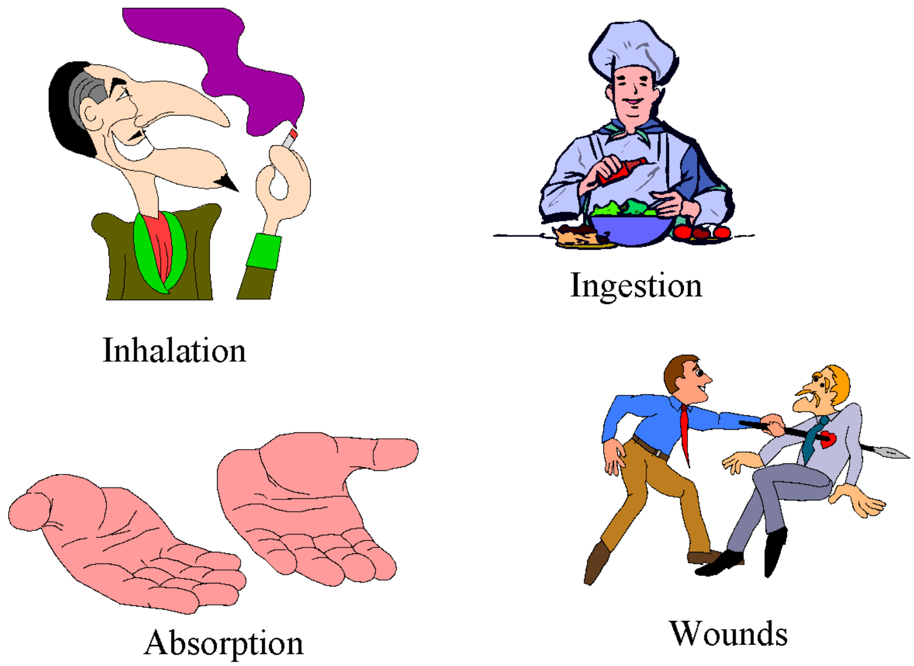


FIGURE 4.3 DIFFERENT MODES OF ENTRY INTO THE BODY

<u>Methods to reduce internal radiation dose</u>

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

Wear respirators properly and when required (if qualified) when applicable.

Report all wounds or cuts before entering any area controlled for radiological purposes.

Comply with the requirements of work documents.

Do not eat, drink, smoke or chew gum in areas controlled for radiological purposes.

<u>Additional methods to reduce dose</u>

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 material present in/on a system that contribute to radiation levels in an area.

E. RADIOACTIVE WASTE MINIMIZATION

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

paper	scintillation vials
gloves	animal waste
glassware	containers
rags	sharps
brooms	mops

Ultimately, this radioactive waste must be disposed. To reduce personnel exposure and reduce costs associated with the handling, packaging and disposal of radioactive waste, it is very important for each employee to minimize the amount of radioactive waste generated.

1. Minimize the materials used for radiological work.

Take only the tools and materials you need for the job into areas controlled for radiological purposes especially contamination areas.

Unpack equipment and tools in a clean area to avoid bringing excess clean material to the job site.

Whenever possible, use tools and equipment identified for radiological work.

If you do not know where to get tools that are to be used for radiological work, ask your supervisor.

Use only the materials required to clean the area. An excessive number of bags, rags, and solvent add to radioactive waste.

2. Segregate radioactive waste from non-radioactive waste.

Place radioactive waste in the receptacles identified for radioactive waste, not in receptacles for non-radioactive waste.

Do not throw radioactive material that may be reused or non-radioactive waste into radioactive waste containers.

Segregate material that may be compacted from material that cannot be compacted.

3. Minimize the amount of mixed waste generated.

Use good housekeeping techniques.

F. RADIATION SAFETY ORGANIZATION

Regulatory agencies require that each licensee shall develop, document, and implement a radiation protection program commensurate with scope and extent of the licensed activities and sufficient to ensure compliance with the provisions of the appropriate regulations.

The licensee shall use, to the extent practicable, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable.

The licensee shall periodically (at least annually) review the radiation protection program content and implementation.

To control the use of radiation sources and maintain compliance, an organization has been established to oversee the program. Many of the members of this organization are identified by name on the license. This organization consists of a Radiation Safety Committee, Radiation Safety Officer, Principle Users (permits), and the individuals authorized to handle radiation sources.

G. RESPONSIBILITIES OF THE ORGANIZATION AND THE USERS

1. The Radiation Safety Committee

The Radiation Safety Committee is charged with the responsibility of assuring that radioactive material is used safely and in accordance with all pertinent State and Federal regulations. The committee is authorized to establish appropriate internal rules and regulations to control and restrict the use of radioactive materials. The Committee consists of representatives from management and research groups involved with different aspects of radiation use. The Radiation Safety Officer is a permanent member of the Radiation Safety Committee. The committee meets at least quarterly. The Chairman is identified by name on the license from the regulatory agency.

2. The Radiation Safety Officer

It is the primary function of the Radiation Safety Officer to assure radiation safety and to ensure compliance with all Federal and State regulations with regard to radiation protection. The Radiation Safety Officer is identified by name on the license from the regulatory agency.

Specific responsibilities include:

a. Assuming responsibility with respect to radiation safety for all programs involving ionizing radiation.

b. Serving as liaison representative with the regulatory agency in matters of licensing, registration, and radiation protection. The Radiation Safety Office will act as a central repository for all records required.

c. He/she reviews applications and granting permission for (or disapproving) the use of and/or the location of radioactivity and radiation-producing devices.

d. Reviewing and approving request for radionuclides; maintaining inventory records.

e. Arranging for disposal of all radioactive waste, and maintaining waste records.

f. Performs all leak tests; maintaining records of sealed sources.

g. Providing personal monitoring equipment (dosimeters) and maintaining exposure records for all personnel; assigning individuals to appropriate internal radiation monitoring programs as necessary; maintaining all radiation exposures in accordance with regulatory requirements.

h. Establishing procedures where necessary for the safe use and handling of radioactivity or radiation producing devices.

I. Specifying all radiation accessories including monitoring, instrumentation and shielding.

j. Authorizing shutdown of a laboratory or modifying laboratory procedures in any area when the health of personnel or the general public is endangered by radiation, or where existing Federal or State regulations may be violated.

k. Reviewing and prescribing special conditions, requirements, and restrictions which may be necessary for the use of radionuclides, or where the health of personnel or the general public may be endangered.

l. Monitoring and performing audits on all facilities utilizing radioactivity or radiation producing devices; ensuring the control of contamination and safe operation with respect to radiation safety, and maintaining records of same.

m. Notify the regulatory agency when the following occurs: loss of control of radioactive material, radiation exposures in excess of regulatory limits, loss of use of the facility, or damage in excess of $5000 (US) or a specific monetary amount due to a radiation accident.

3. Radiation Safety Assistant (Radiation Support Staff/Personnel)

The Radiation Safety Officer may delegate responsibility for technical radiation protection activities to personnel working for him/her and under his/her direct supervision. Training for individuals performing health physics (radiation safety) functions should be provided by the Radiation Safety Officer.

These functions may include but are not limited to:

a. Reviewing purchase request for completeness and correctness.

b. Receiving and check-in of radioisotope shipments.

c. Processing and arranging disposal of radioactive waste.

d. Monitoring such as laboratory surveys, bioassays, and air sampling.

e. Personal monitoring equipment as required by the Radiation Safety Officer.

f. Performing calibration of survey instrumentation.

4. Responsibilities of Principal Users

Principal Users are responsible for the safe use and handling of radionuclides by all personnel operating under their supervision.

Specific responsibilities include:

a. Carrying out the radiation safety program as defined in the Radiation Safety Manual.

b. Familiarity with appropriate regulations and procedures for the safe use and handling or radioactive materials.

c. Notifying persons entering the research areas of the presence of radioactive material or radiation and the necessary precautions.

d. Instructing subordinates and training them in safety procedures required for handling radioactive material specific to laboratory/project operations.

e. Maintaining contamination surveys and inventory records for the laboratory.

f. Notifying the Radiation Safety Officer in the event of radiation hazard involving contamination of the laboratory, loss of control of radioactive material, or exposure of personnel.

g. Following proper procedures in procurement, storage, security, transfer, and disposal of radioactive material.

5. Responsibilities of Individual Users

Individual users are responsible for:

a. Familiarity with appropriate regulations and procedures for the safe use and handling of radioactive materials.

b. Notifying the Principal User and the Radiation Safety Officer in the event of a spill, personnel contamination, or loss of control of radioactive material.

c. Notifying persons entering the research areas of the presence of radioactive material or radiation.

d. Maintaining laboratory housekeeping in areas utilizing ionizing radiation.

e. Following proper procedures in procurement, storage, transfer, and disposal of radioactive material.

H. TRAINING

The facility provides radiation safety training to all employees. The training includes an orientation lecture, a copy of the Radiation Safety Manual, and an annual refresher course provided by the Radiation Safety Officer. Additional training may be required for a specific audience if the Radiation Safety Committee and/or the Radiation Safety Officer feel it is necessary to maintain exposures as low as reasonably achievable.

Section 5. Personnel Monitoring Programs

LEARNING OBJECTIVES:

STATE the purpose of each of the personnel dosimeter devices used at the site.
IDENTIFY the correct use of each of the personnel dosimeter devices used.
STATE the purpose of each type of internal monitoring method used.
IDENTIFY worker responsibilities concerning internal monitoring programs.
STATE the method for obtaining radiation dose records.
IDENTIFY worker responsibilities for reporting radiation dose received from other sites and from medical applications.

INTRODUCTION

To assess each employee's external and internal exposure to ionizing radiation, special types of monitoring equipment are used. Various types will be used depending on the radiological hazards present. Each type needs to be handled correctly.

A. EXTERNAL DOSIMETRY

Various types of external dosimeters are used to measure personnel dose to external sources of radiation. Most programs receive their monitoring devices from various vendors (companies who specialize in dosimetric devices). These vendors evaluate the information recorded on the monitoring devices and provide the associated reports to their customers. They produce several different types of monitoring devices depending on the customer's application. The purpose of each dosimeter device must be known and understood so that each can be used correctly.

Monitors are generally in one of two forms. Either they are film badges or Thermaluminescent Dosimeters (TLD). Film badges are less popular in recent times. Each has unique values. The film badge can provide information such as beta tracks, partial exposure, and energy distribution. It can also be reviewed over again at a later date. The TLD can be applied to a very small location due to its size.

● Wear dosimeters at all times in areas controlled for radiological purposes and when required by signs, work permits or radiation safety personnel. Whole-body dosimeters must be worn on the chest area between the waist and the neck.

- When pocket or electronic dosimeters are required, they shall be worn within close proximity to the primary dosimeter.
- While in an area controlled for radiological purposes, take proper actions if a dosimeter is lost, off scale, damaged or contaminated.
- These actions include:
  - Place work activities in a safe condition
    - Alert others
    - Immediately exit the area
    - Notify Radiological Control personnel
    - Know the proper dosimeter storage location.
    - Return dosimeters for processing periodically. Personnel who fail to return dosimeters must be restricted from continued radiological work.
    - Wear dosimeters only at site for which they are issued.

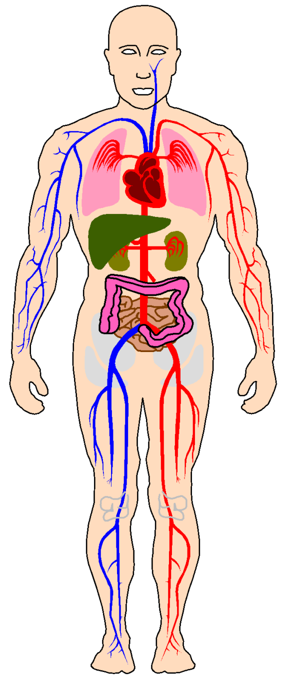
B. INTERNAL MONITORING

Potential sources of internal exposures can be placed into two categories. One category is natural radioactivity in all food and water, the air, and medical procedures that use radioactive materials and radioactive contamination.

The other category is accidental or inadvertent internal uptake (incorporation into the cells) of radioactive material (internal contamination) that can cause additional dose to the whole body or individual organs.

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 and/or bioassay samples may be used. From this measurement, an internal dose may be calculated. Whole body counters are external counting systems. The system is placed near the area of the body that the radioactivity is expected to be (i.e., the thyroid in the neck for the use of radioactive iodine). The bioassay is a method of evaluating samples collected from the individual. This would include urine, blood, tissue, etc.

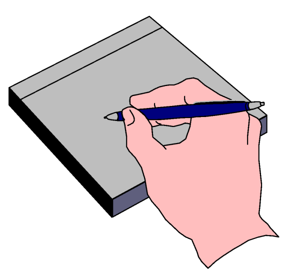


The purpose of each type of internal monitoring method is to maximize the possibility of detection for the nuclide involved.

It is each worker's responsibilities to participate in the monitoring program according to the established procedures.

C. RADIATION DOSE RECORDS

- Methods for obtaining dose records usually involve a written request.
- Report radiation doses received from other facilities and medical applications.
- Notify Radiological Control personnel prior to and following of any radiation dose received at another facility so that dose records can be updated.
- Medical applications (excluding routine medical and dental x rays) are not included as occupational exposures.
- Dose record reports.
- Personnel (non-visitors) who are monitored with dosimeters will be provided an annual report of their radiation dose.
- Upon request, personnel should receive a current radiation dose record.
- Terminating personnel will receive a report of the radiation dose received at that site.



D. DOSIMETRY PROGRAM

A monitoring program has been established to determine and record the absorbed dose of staff and visitors, and to ensure compliance with regulations. The program consists of:

1. Dosimeters issued based upon exposures.

Dosimeters shall be issued to all staff who are likely to receive 300 mrem/quarter or 3 mSv/ quarter absorbed dose to the whole body, 400 mrem/quarter or 4 mSv/quarter absorbed dose to the skin of the whole body, or 900 mrem/quarter or 9 mSv/quarter to the hands, forearms, feet, or ankles.

2. Issuing dosimeters to new employees

Dosimeters shall be issued as soon as possible to employees, but before they begin work handling radiation sources. Dosimeters issued will be dependent on the isotopes used and the procedures involved. However, all radiation workers will be issued whole body dosimeters.

3. Responsibility of the wearer

Any dosimeter issued to an individual will become the responsibility of the individual. Dosimeters must never be taken from the facility except under the direction of the Radiation Safety Officer. All dosimeters will be stored in a radiation free area when not worn. Control dosimeters will be used to monitor environmental exposure to all films when they are in storage or in transit.

4. When and how to wear the dosimeters

Working with RAM without appropriate dosimeters in place is prohibited. Dosimeters will be worn in the following manner:

a. Whole body dosimeters -- on the front of the torso, in a location where they are unlikely to become contaminated.

b. Extremity dosimeters (ring) -- on any finger of hand most likely to receive the greatest exposure. The ring label is worn inside.

5. Dosimetry records.

- Accounting records shall be kept of the arrival and shipping of all dosimeters.
- All dosimeters shall be surveyed for contamination prior to shipping to the vendor.
- All lost or damaged dosimeters will require dosimeter estimates whenever possible.
- All estimates shall involve an interview with the individual being monitored, so that an agreement on the estimate is reached. Then and only then will the vendor be notified by letter (legal document).

6. Monitoring of visitors

Visitors who receive occupational radiation exposure during their visit will be issued temporary dosimeters. Records will be kept of each visitor's name, dates of exposure, social security number, date of birth and exposure received.

7. Dosimetry reports to workers

Dosimetry reports will be examined, initialed and dated by the Radiation Safety Officer when they are received from the vendor. Exposure notification will be sent to anyone having been exposed. Regulations requires individual dosimetry data be made available to persons who are monitored. However, dosimetry reports are confidential, and should not be released to anyone outside the facility except regulatory inspectors.

8. Spare dosimeters and damaged dosimeters

Spare dosimeters shall be issued to new employees working for 2 weeks or less or as replacements for lost or damaged dosimeters.

E. BIOASSAY PROCEDURE FOR THE UPTAKE OF IODINE-125

Iodine-125 presents a special risk to the individual working with or near unsealed sources due to its ability to translocate. Special procedures have been established to determine the thyroid burden from Iodine-125 deposited internally by inhalation, ingestion, or absorption through the skin. The actual procedures are maintained and administered by the Radiation Safety Officer.

Monitoring schedules have been established for individuals handling Iodine-125 between 24 and 72 hours after the use of specific quantities. These quantities differ if the form is volatile or not.

F. BIOASSAY PROCEDURE FOR THE UPTAKE OF H-3

Handling tritium also presents a special risk. Approximately half of the uptake experienced by an individual from tritium is obtained by absorption through the skin. To determine the whole-body burden from H-3 deposited internally by inhalation, ingestion or absorption through the skin, a special monitoring program has been established.

Bioassays are performed within one week (of primary use) for persons using H-3 in unsealed form if the quantity handled at any one time or cumulatively over a month's period is 100 millicuries (3.7×10^9 Bq) or more as precursors of deoxyribose nucleic acid, or 1 curie (3.7×10^{10} Bq) or more in other forms of tritiated compounds.

The actual procedures are maintained and administered by the Radiation Safety Officer.

Section 6. Radioactive Contamination Control

LEARNING OBJECTIVES:

DEFINE fixed, removable and airborne contamination.
DEFINE sources of radioactive contamination.
STATE the appropriate response to indicators of potential area contamination or personnel contamination alarms.
IDENTIFY methods used to control radioactive contamination.
IDENTIFY the proper use of protective clothing.
EXPLAIN the purpose and use of personnel contamination monitors.
IDENTIFY the normal methods used for decontamination.

INTRODUCTION

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

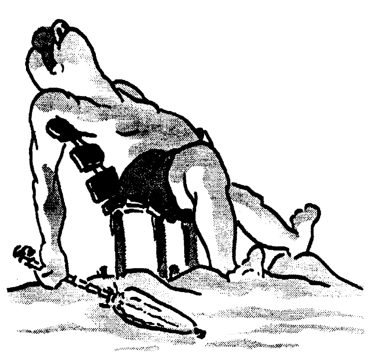
Contamination control is one of the most important aspects of radiological protection. Using proper contamination control practices will help ensure a safe working environment. It is important for all employees to recognize potential sources of contamination as well as to use appropriate contamination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

A. COMPARISON OF RADIATION AND RADIOACTIVE CONTAMINATION

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

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

Radiation is energy. Contamination is material.



Exposure

Contamination

You can be exposed to radiation without contamination. If you are contamination you will continue to be exposed as long as the contamination is there.

B. TYPES OF CONTAMINATION

Radioactive contamination can be fixed, removable or airborne.

1. Fixed contamination

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

2. Removable/transferable contamination

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

3. Airborne contamination

Contamination suspended in air.

C. SOURCES OF RADIOACTIVE CONTAMINATION

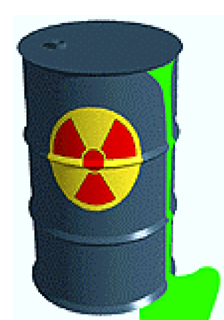
Radioactive material can be spread to unwanted locations. There are several sources and indicators of radioactive contamination.

1. Leaks or breaks in radioactive systems

Hot particles are small, sometimes microscopic pieces of radioactive material that are highly radioactive. They can cause a high, localized radiation dose in a short period of time if they remain in contact with skin/tissue. Hot particles may be present when contaminated systems leak, are opened or when machining, cutting, or grinding highly radioactive materials. Work activities that present exposure risks to workers from leaks or breaks in radioactive systems include:

- Opening radioactive systems without proper controls.
- Airborne contamination depositing on surfaces.
- Leaks or tears in radiological containers such as barrels, plastic bags or boxes.
- Poor housekeeping in contaminated areas.
- Excessive motion or movement in areas of higher contamination.
- Sloppy work practices such as cross-contamination of tools, equipment or workers.

2. Indicators of possible contamination



- Leaks, spills, standing water
- Dusty, hazy air
- Damaged radiological containers
- Spurious or unexplained personnel contamination at exit points
- Higher than normal background on personnel contamination survey devices
- Airborne monitor alarms

D. CONTAMINATION CONTROL METHODS

Control of radioactive contamination can be achieved by proper personnel radiological practices and engineering controls. By controlling contamination, the potential for internal exposure and personnel contamination can be decreased.

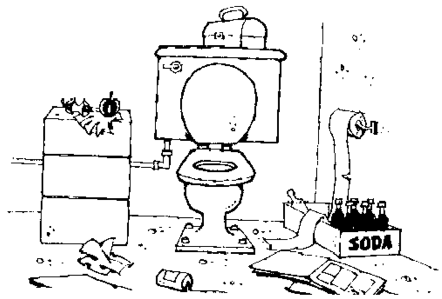
If the presence of loose contamination is discovered, decontamination is a valuable means of control. In some situations, this is not always possible due to:

- Economic conditions: Cost of time and labor to decontaminate location outweighs the hazards of the contamination present.
- Radiological conditions: Radiation dose rates or other radiological conditions present hazards that far exceed the benefits of decontamination.
  Therefore, other means of control must be initiated when decontamination is not possible.

1. Employ preventive methods to control radioactive contamination.

- Identify and repair leaks before they become a serious problem.
- Establish adequate work controls before starting jobs.
- Discussing measures that will help reduce or prevent contamination spread before the work begins.
- Change out gloves or protective gear as necessary to prevent cross-contamination of equipment.
- Set-up pre-staging areas to prevent contamination spread from work activities:
- Cover equipment below a work area to prevent dripping contamination onto cleaner areas.
- Cover/tape handling tools or equipment used during the job to minimize decontamination after the job (i.e., tape up a pipette before use).
- Good work practices such as good housekeeping and cleaning up after jobs.

Most laboratories do not use amounts of radiochemicals that pose an external dose risk. However, area contamination can happen even when materials are carefully handled. Have in the work area only those things needed for the task at hand. Keep the laboratory clean and orderly. **"Good Housekeeping"** is the prime factor in an effective contamination control program. It involves the interactions of all workers within the laboratory or group. Each individual must be dedicated to keeping "his/her house clean" to control the spread of contamination.



Every possible effort should be made in all operations to confine the spread of radioactive materials to the smallest possible area.

A sound preventive maintenance program can prevent many radioactive material releases.

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

Regardless of the precautions taken, radioactive materials will occasionally escape and contaminate an area.

Radiation workers should always be alert for potential violations to the basic principle of contamination control: use of improper contamination control methods, bad work practices, basic rule or standard operating procedure violations, radioactive material releases or liquid spills.

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

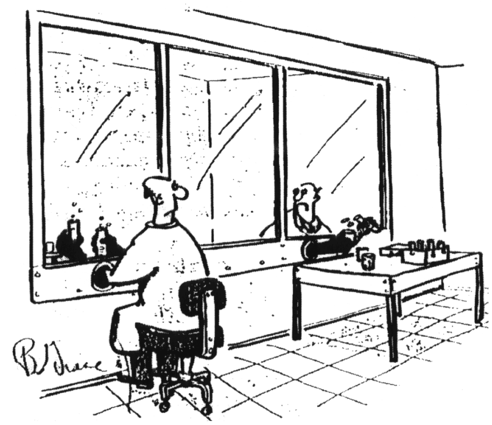
2. Engineering control methods

Ventilation is designed to maintain airflow from areas of least contamination to areas of most contamination (e.g., clean to contaminated to highly contaminated areas). Slight negative pressure is maintained on buildings where potential contamination exists.

It is possible to use high efficiency particulate filtration (HEPA) that removes radioactive particles from the air.

Splash control is of paramount importance for quantities under 5 millicuries of ^{32}P. A μCi (3.7×10^4 Bq) spread over 1 cm^2 of skin for 6 hours exceeds the annual exposure limit (8.86 rad/hr x 6 hr = 53 rads or 0.53 Gy).

3. Containment



Containment generally means using vessels, pipes, cells, glove-bags, glove-boxes, tents, huts and plastic coverings to control contamination by containing it.

4. Personnel protective measures

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

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

Full protective clothing generally consists of laboratory coats, surgical gloves, and shoe covers.

5. Proper Use

- Inspect all protective clothing for rips, tears or holes prior to use.

- Personal effects such as watches, rings and jewelry should not be worn in contaminated areas.
- Supplemental dosimeters, such as ring badges, should be worn underneath the protective gloves.
- After donning protective clothing and working in contaminated areas, do not go to other locations (i.e., outside the laboratory) with the protective clothing.
- Contact Radiological Control personnel if clothing becomes ripped or torn.
- Respiratory equipment is used to prevent the inhalation of radioactive materials. This training course <u>does not</u> qualify a radiation worker to wear respiratory equipment.

E. CONTAMINATION MONITORING EQUIPMENT

Contamination monitoring equipment is used to detect radioactive contamination on personnel. The following are types and use of hand-held contamination monitors.



- Verify the instrument is on, set to the proper scale, and the audio will be heard.
- Survey hands before picking the probe up.
- Hold probe approximately ½" from surface being surveyed for beta/gamma radiation.
- Move probe slowly over surface, approximately 2" per second.
- Proceed to survey in the following typical order (for a complete survey):
    - Start at the head (pause at mouth and nose for approximately 5 seconds if airborne contamination is a concern), neck, and shoulders
    - Arms - pause at each elbow
    - Chest, abdomen and back
    - Hips and seat of pants
    - Legs - pause at each knee
    - Shoe tops
    - Shoe bottoms
    - Finally survey the personal and supplementary dosimeters.
- The whole-body survey should take 2-3 minutes per survey with an instrument.
- If the count rate increases during the survey, pause for 5-10 seconds over the area to provide adequate time for instrument response. Carefully return the probe to holder.
- If contamination is indicated, remain in the area and notify Radiation Safety personnel. Minimize cross contamination (such as putting a glove on a contaminated hand) while waiting for Radiation Safety personnel to arrive.

F. DECONTAMINATION

Decontamination is the removal of radioactive materials from locations where it is not wanted. This does not result in the disappearance of radioactive material but involves the removal of the radioactive materials to another location.

- Personnel decontamination is normally accomplished using mild soap and lukewarm water.
  - Material decontamination is the removal of radioactive materials from tools, equipment, floors and other surfaces in the work area.

Section 7. Radiological Posting and Controls

LEARNING OBJECTIVES:

STATE the purpose of and information found on standard operating procedures.
IDENTIFY the individual's responsibilities in using standard operating procedures.
IDENTIFY the colors and symbols used on radiological postings, signs and labels.
DEFINE all types of Radiation, Contamination, Airborne Radioactivity and Radioactive Material Areas.
STATE the entry requirements for working in and exiting areas controlled for radiological purposes.
STATE the radiological and disciplinary consequences of disregarding radiological postings, signs and labels.
STATE the radiological and disciplinary consequences of unauthorized removal of relocation of radiological postings, signs and labels.

INTRODUCTION

The previous sections discussed some very important background radiological information and radiation dose and contamination control methods. This section will apply this information to the working environment.

A. STANDARD OPERATING PROCEDURES

Standard operating procedures are used to establish radiological controls for areas where radiation sources are handled or stored. They serve to inform workers of area radiological conditions, entry requirements into the areas, special and general radioisotope handling, and provide a means to relate radiation doses received by workers due to specific work activities.

There are two types of Radiological Work Permits depending on the radiological conditions. General operating procedures are used to control routine or repetitive activities such as general handling techniques and inspections in areas with historically stable radiological conditions. Job specific procedures are used to control non-routine operations or work in areas with changing radiological conditions.

1. Information found on Radiological Work Permits consists of:

a. Description/location of work

b. Radiological conditions (this information may also be determined from area radiological survey maps/diagrams or the radiological posting for that area)

c. Dosimeter requirements for the work

d. Pre-job instruction (as applicable). Pre-job instruction generally consist of workers and supervisor(s) discussing various radiological aspects of the job so as to minimize radiological exposure and unplanned situations

e. Required level of training

f. Protective clothing/equipment requirements

g. Radiological Control coverage requirements and stay time controls, as applicable

h. Limiting radiological conditions that may void the operation

i. Special dose or contamination reduction considerations

j. Special personnel surveying considerations

k. Technical work document and other unique information for the task.

l. Date of issue/expiration (if applicable)

m. Authorizing signatures (if applicable)

2. Worker Responsibilities

Workers are responsible to have read and understood the procedure prior to handling radiation sources within the procedure. If, in the judgment of a worker, the procedure is not correct or the information is not clear and understandable, the job should not be started. Instead, the supervisor or Radiation Safety personnel should be contacted. Workers must obey any instructions written in the procedure. Substitutions must never be made for specified requirements.

B. RADIOLOGICAL POSTINGS

1. Purpose

Radiological postings are used to alert personnel to the presence of radiation and radioactive materials. All entrances to the controlled areas shall be clearly marked to indicate that the radioactive materials or radiation producing devices are present.

2. Posting Requirements

Areas Controlled for Radiological Purpose will be designated with a magenta (or black) standard three-bladed radiological warning symbol on a yellow background. Additionally, yellow and magenta ropes, tapes, chains, or other barriers will be used to denote the boundaries. See figure 7.1.

FIGURE 7.1 RADIATION SYMBOL

a. The barriers will be clearly visible from every side. Entrance points to those areas will have signs (or equivalent) stating the entry requirements, such as "Personnel Dosimeters are Required." Additionally, the radiation dose rate, contamination level and/or airborne radioactivity concentration will be included on or near each posting, if applicable when higher levels are experienced.

b. Before entering an area controlled for radiological purposes, read all the signs. Since radiological conditions may change, the signs must also be changed to reflect the new conditions. Yesterday's sign may be replaced with a new one today.

c. In some cases, more than one radiological hazard may be present in the area. Each must be posted (e.g., Radiation Area, Contamination Area, Airborne Radioactivity Area.)

3. Types of areas controlled for radiological purposes.

The following areas are referred to as radiological areas. Radiological area is a generic term referring to portions of Radiological Buffer Areas.

a. Radiological Buffer Area (BRA) - A boundary area surrounding other radiological areas containing greater radiological hazards such as Radiation, Contamination and Airborne Radioactivity Areas.

Requirements for entry and working in buffer areas include:

- Specialized training and personal dosimetry
- Eating, drinking, smoking or chewing prohibited
- Obey any posted, written or oral requirements including "Evacuate", or "Stop Work" orders from Radiation Safety personnel

Stop Work orders are usually a result of one or more of these problems:

- Inadequate radiological controls
- Radiological controls not being implemented
- Sometimes labels or tags are used to warn of specific radiological hazards. Also, radioactive material may be stored in containers that are marked appropriately.

b. Hot Spots

A hot spot is a localized source of radiation or radioactive material sometimes found in equipment. The radiation levels at that point are typically much higher than the surrounding area. Avoid those areas. The posting will indicate:

CAUTION - HOT SPOT

- Report to Radiation Safety personnel if radiological controls are not adequate or are not being followed.
- In addition, report any unusual conditions such as leaks or spills, dusty, hazy air, and alarming radiation safety instrumentation to Radiation Safety personnel.
- If a spill of radioactive material should occur, it must be controlled immediately to prevent the spread of contamination. To assist in controlling the spill, use the **SWIMS** method:

    - **Stop** or secure the operation causing the spill.
    - **Warn** others in the area.
    - **Isolate** the spill if possible
    - **Minimize** individual exposure and contamination
    - **Secure** unfiltered ventilation, as appropriate
    - Notify Radiation Safety personnel and your supervisor

Be aware of changing radiological conditions. Make sure that activities do not create radiological problems for others, and be alert that the activities of others may change the radiological conditions.

Requirements for Exiting

- Monitoring requirements for exiting are site specific
- Before entering a clean area, workers must monitor for contamination per instructions.
- Personal items, such as notebooks, papers or flashlights must also be monitored for contamination and are subject to the same monitoring requirements as the person carrying them.
- Personnel surveying shall be performed prior to washing or showering.

c. Radiation Area

An area is designated a Radiation Area (see figure 7.2) when radiation dose rates are $>$ 5 mrem/hr but $\leq$ 100 mrem/hr (0.05 mSv but $<$ 1 mSv) at 30 centimeters from the source of radiation. The postings/signs will indicate:

CAUTION

RADIATION AREA

Personnel Dosimetry Required for Entry

FIGURE 7.2 RADIATION AREA SIGN

All personnel entering such areas must have completed Radiation Worker Training to include the following established standard operating procedures.

Do not loiter. Always practice ALARA. If unanticipated elevated radiation levels are indicated as identified by off scale dosimeter, radiological alarms or other indicators; then:

- Stop work
- Alert others
- Immediately exit the area
- Notify Radiation Safety personnel
- Follow the requirements for exiting

d. High Radiation Area

An area is designated High Radiation Area (See figure 7.3) when radiation dose rates are > 100 mrem/hr (1 mSv) at 30 centimeters from the source of radiation, but ≤ 500 rad/hr (≤ 5 Gy/hr) at 100 centimeters from the source of radiation. The postings/sign will indicate:

DANGER

HIGH RADIATION AREA

Personnel Dosimetry, Supplemental Dosimeters and

Radiological Work Permit Required for Entry

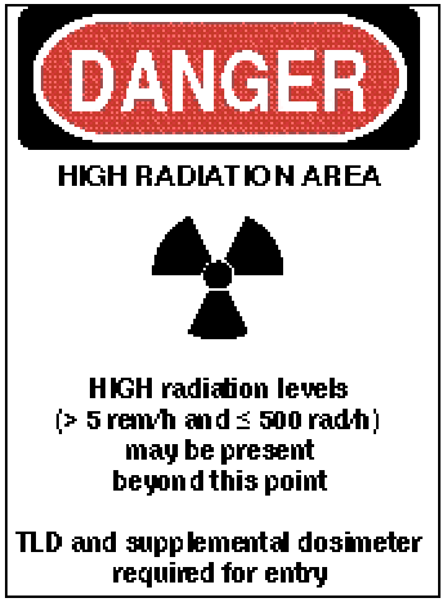


FIGURE 7.3 DANGER HIGH RADIATION AREA SIGN

e. Very High Radiation Area

An area is designated Very High Radiation Area when radiation dose rates are >500 rad/hr (> 5 Gy/hr) at 100 centimeters from the source of radiation. The postings/signs will indicate:

GRAVE DANGER - VERY HIGH RADIATION AREA

Special Controls Required for Entry

Entry requirements for High Radiation Area and Very High Radiation Area include specialized training and procedures:

- Personnel and supplemental dosimeters worn.
- Survey meter or dose rate indicating device used.
- Access points secured by control devices.

Additional requirements where dose rates are greater than 0.1 rem/hr are:

- A formal radiological review of non-routine or complex work activities.
- Determining of worker's current exposure.
- A pre-job brief, as applicable.
- Additional radiological control coverage implemented.

Requirements for working in a Radiation Area also apply when working in High and Very High Radiation Areas.

f. Contamination/Airborne Radioactivity Areas

<u>Contamination Area</u>

An area where contamination levels exceed specific limits is referred to as a Contamination Area (See figure 7.4). The posting/signs will indicate:

CONTAMINATION AREA

FIGURE 1.4 RADIATION CONTAMINATED AREA SIGN

High Contamination Area

An area where contamination levels exceed specific limits is referred to as a High Contamination Area. The posting/signs will indicate:

DANGER

HIGH CONTAMINATION

Fixed Contamination Area

A Fixed Contamination Area is an area or equipment with no removable contamination but which contains fixed contamination levels exceeding specified limits.

The postings/signs will indicate:

CAUTION

FIXED CONTAMINATION

Airborne Radioactivity Area

An area where airborne radioactivity exceeds specified limits is called an Airborne Radioactivity Area. The postings/signs will indicate:

CAUTION

AIRBORNE RADIOACTIVITY AREA

Requirements for entry into Contamination Areas and Airborne Radioactivity Areas include:

- Radiation Worker Training.
- Personnel dosimeters
- Worker signature on standard operating procedure (if applicable)
- Protective clothing/equipment as required by the standard operating procedure
- A pre-job briefing for High Contamination Area and Airborne Radioactivity Area

Instructions for working in Contamination Areas and Airborne Radioactivity Areas include:

- Avoid unnecessary contact with contaminated surfaces.
- Secure hoses electrical lines, tubes and cables to prevent them from crossing in and out of contamination area.
- When possible, wrap or sleeve materials and equipment.
- Place contaminated tools and equipment inside plastic bags when work is finished.
- DO NOT touch unexposed skin surfaces. Highly contaminated material left on the skin for an extended period of time can cause a significant localized dose to the skin.
- Avoid stirring contamination up since it could become airborne.

Smoking, eating or chewing is not allowed in Contamination, High Contamination and Airborne Radioactivity Areas.

Exit immediately if an injury occurs which allows contamination inside the body.

Requirements for exiting

Exit only at the step-off pad. A step-off pad provides a "barrier" between contaminated and other areas to prevent or control the spread of contamination between areas.

If more than one step-off-pad is used, the final step-off-pad is "clean", it is outside the exit point, and it is adjacent to the control boundary.

Remove protective clothing carefully.

Perform a whole-body survey. If contamination is indicated: stay in the area, notify Radiation Safety personnel, and take actions to minimize cross-contamination (e.g., put a glove on a contaminated hand).

After exiting and monitoring, it is a good radiological practice to wash hands prior to performing such activities such as eating, drinking, chewing, applying make-up, etc.

g. Radioactive Materials Area

An area that is established to indicate areas where radioactive materials are used, handled or stored is a Radioactive Materials Area.

Material stored there generally consists of equipment, components and materials that have been exposed to contamination. Sealed or unsealed radioactive sources are also included.

The postings/signs will indicate:

CAUTION

RADIOACTIVE MATERIALS AREA

<u>Requirements for entry/exit</u>

Entry requirements into a Radioactive Materials Area where the whole body dose rate exceeds 5 mrem/hour (0.05 mSv) or contamination levels exceed specified limits would be the same as for entry into a Radiation Area or Contamination Area, depending on the radiological hazard present.

C. RESPONSIBILITIES OF THE WORKER ASSOCIATED WITH POSTINGS, SIGNS, AND LABELS

It is each worker's responsibility to read and comply with all the information identified on radiological postings, signs and labels. Disregarding any of these or removing/relocating them without permission can lead to unnecessary or excessive radiation exposure and/or personal contamination. If any type of material used to identify radiological hazards is found outside an area controlled for radiological purposes, it should be reported to Radiation Safety personnel immediately.

D. FACILITY MAPS

Maps with locations of radiation sources indicate the boundaries of the controlled areas. Boundaries are defined by walls, doorways, and by tape stripes for areas where physical boundaries are not present.

Section 8. Radiological Emergencies

LEARNING OBJECTIVES:

IDENTIFY the correct responses to emergencies and/or alarms.
STATE the possible consequences for disregarding radiological alarms.
STATE the site administrative occupational emergency radiation dose limits.
IDENTIFY the essential elements of an effective emergency response plan.

INTRODUCTION

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

A. TYPES OF EMERGENCIES

In areas where the exposure levels are above specified limits, equipment that monitors abnormal radiation exposure levels and airborne contamination levels is placed in strategic locations throughout facilities. It is essential for the worker to be able to identify the equipment and alarms and respond appropriately to each.

1. Small Incidents

An incident is small if it meets all of the following conditions:

- A material is released whose nature and potential hazards are known.
- The release presents no actual or potential threat to human health or the environment.
- If the release can be cleaned up by one or two people in less than one hour.
- The incident results in nothing more serious than a minor injury requiring simple first aid.

2. Large Incidents

An incident is considered large if any one or more of the following conditions occur:

- Potential contamination of ground water.
- Fire or explosion.

- An incident is regarded as unsafe to manage when the aid of the Fire Department is required for support.
- Release of material that cannot be identified.
- Release of material that cannot be cleaned up by two people in less than one hour.
- Injuries result that require medical treatment other than first aid.
- Incident requires evacuation of the building or the facility.
- Released material migrates to a storm drain or sewer.

B. DISREGARD FOR RADIOLOGICAL ALARMS

Disregarding any of these radiological alarms may lead to possible excessive personal exposure, and the unnecessary spread of contamination.

C. RADIOLOGICAL EMERGENCY SITUATIONS

Working in a radiological environment requires more precautionary measures than performing the same job in a non-radiological setting. This premise holds true especially if an emergency arises during radiological work. Types of emergencies could be:

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

D. CONSIDERATIONS IN RESCUE AND RECOVERY OPERATIONS

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

Rescue and recovery operations that involve radiological hazards can be a very complex issue with regard to the control of personnel exposure. The type of response to these operations is generally left up to the officials in charge of the emergency situation. The judgment of the officials is guided by many variables which include determining the risk versus the benefit of the action, as well as how to involve other personnel in the operation. If the situation involves a substantial personal risk, volunteers will be used. The use of volunteers will be based on their age, experience, and previous exposure.

The regulatory emergency response for these personnel is as follows:

- Protecting major property where the lower dose limit of 5 rem (0.05 Sv) is not practicable - 10 rem (0.1 Sv).
- Lifesaving or protection of large populations where the lower dose limit is not practicable - 25 rem (0.25 Sv).
- Lifesaving or protection of large population - only on a voluntary basis to personnel fully aware of risks involved - greater than 25 rem (0.25 Sv).
  Most facilities establish administrative emergency dose limits that are more conservative than regulatory limits.

E. EMERGENCY PROCEDURES IN ACCIDENTS WITH RADIOACTIVE MATERIALS

Emergencies resulting from accidents caused when working with radioactive materials may range from minor spills of small quantities involving no radiation hazard, to radiation involving serious hazards to personnel and the possibility of bodily injury. Because accidents involving radioactive materials are spontaneous occurrences and often involve complicating factors, set rules for emergency procedures cannot be laid down to cover all possible situations. In any emergency, however, the primary concern is always the protection of laboratory personnel from radiation hazards. Once it is ascertained that no radiation hazard exists to personnel, and existing hazards are under control, the next major concern is confinement of contamination to the immediate area of the accident, and finally, its removal.

If an accident occurs involving radioactive materials (e.g., spill, ingestion, inhalation, or overexposure), notify the Radiation Support Staff (Radiation Safety Officer) and a supervisor as promptly as possible. Take the necessary precautions to avoid involvement of the other personnel in the radiation hazard or spread the contamination. Remain in the immediate area until the Radiation Safety Officer or an appointee arrives.

F. SPILLS AND ACCIDENTS

1. Spills involving no contamination of personnel

a. Notify all other persons in the area at once of the spill.

b. Permit only the minimum number of persons necessary to deal with the spill into the area, making certain that other personnel involved in the accident remain nearby. This will help avoid the possible spread of contamination into the areas.

c. Confine the spill immediately.

Liquid Spills

- Don protective gloves.
- Drop absorbent materials or paper on the spill.

Dry Spills

- Don protective gloves.
- Dampen thoroughly with wet absorbent paper, taking care not to spread the contamination.

d. Notify the Radiation Safety Officer as soon as possible. Do nothing further to remove the contamination until radiation safety personnel arrive.

e. Permit no one to resume work in the area until approval is obtained from the Radiation Safety Officer. The Radiation Safety Officer or the Radiation Support Staff will coordinate the decontamination and monitoring of personnel and the area.

2. Spill involving radiation hazard to personnel

a. Notify all persons not involved in the spill to evacuate the area immediately, but to remain in the local area (hallway or adjacent laboratory) until monitored for contamination. Allow no one except Radiation Support Staff or the Emergency Response Team into the area.

b. Make no immediate attempt to clean up the spill. If the spill is liquid, and the hands are protected, put the container in the upright position.

c. Spills involving contamination of personnel or clothing:

- If the spill is on the skin, flush thoroughly with water.
- If the spill is on clothing, discard outer or protective clothing at once, including shoes. Place these articles on absorbent paper or in plastic bags.
- In the case of internal contamination from ingestion of radionuclides, contact the Radiation Safety Officer immediately. If ingestion of radioactivity is apparent or suspected, the Radiation Safety Officer will determine whether or not a physician should be consulted.

d. Make sure the fume hood is “on” and the sash is open if the spill is in the room. If the spill is in the fume hood, leave the sash slightly open and make sure the fume hood is left “on”.

e. Evacuate the room, and prohibit entrance into the contaminated area.

f. Do not leave the area.

g. Permit no one to resume work until approval is obtained from the Radiation Safety Officer.

h. Have someone not involved in the accident notify the Radiation Safety Officer as soon as possible, relating all details of the accident.

i. Under no circumstances should an untrained person attempt to examine or decontaminate personnel in the area.

If the individual is only contaminated internally, he or she will present no hazard to Emergency Medical Personnel unless the individual has a great deal of radioactive material on his/her body (i.e., a highly radioactive object that may be embedded ion or on the individual, or an ingestion of a highly radioactive liquid).

Always assume the individual is internally contaminated until proven otherwise, especially if the individual has external contamination. Contamination near any cavity of the body constitutes reason to suspect possible internal contamination.

Treat all body fluids as potentially radioactive until proven otherwise. Nasal secretions, stool, urine, vomit, blood-soaked dressings are all substances that may be contaminated. These and any other potential sources should be saved for isotopic analysis.

3. Accidents involving radioactive mists, dust, fumes and organic solvents

a. Notify all persons to vacate the room immediately. They should remain in the immediate area (hallway or adjacent laboratory).

b. Ensure that the hood is operating before leaving the room.

c. Leave the room and join the other persons involved in the accident.

d. Have the Radiation Safety Officer notified at once, relating details of the accident.

e. Ascertain that all doors giving access to the room are closed. Under no circumstances should anyone be allowed to enter the room.

f. Report all those suspected or known to have inhaled radioactivity to the Radiation Safety Officer.

g. Do not re-enter the room until approval is obtained from the Radiation Safety Officer.

4. Injuries to personnel involving radiation hazards

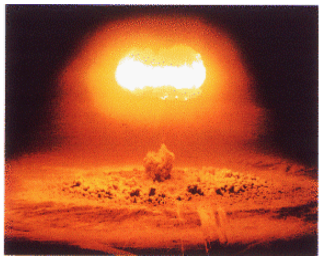
a. Wash minor wounds immediately, under running water, spreading the edge of the cut or gash to permit complete flushing. Contact the Radiation Safety Officer. Do not resume work until approval is obtained from the Radiation Safety Officer. The first concern is for the injured individual. If time permits and the injury is minor, attempt to save the water from the washing.

b. If injury is more serious, such as a broken bone or severe burn, have the Radiation Safety Officer notified immediately. Do nothing that would further complicate the injury.

c. In cases involving a radiation injury, a physician qualified to treat radiation injuries should be contacted if necessary.

d. No person involved in a radiation injury is to return to work without the consent of the Radiation Safety Officer.

2. Fires involving radiation



a. Notify all persons in the area at once.

b. Attempt to extinguish the fire if there is no threat of a radiation hazard, the fire can be fought with no hazard to life, and you have had the appropriate fire extinguisher.

c. Notify the Radiation Safety Officer as soon as possible.

d. All firefighting and other emergency procedures involving radioactivity will be guided by the advice of the Radiation Safety Officer and Radiation Support Staff.

G. Elements of an Emergency Response Plan

Each employer must develop an emergency response plan for emergencies. The plan must be in writing and available for inspection.

1. Pre-planning and preparation before an incident.

Pre-emergency planning and coordination with outside resources, agencies and individuals who may be affected by such emergencies must be accomplished to minimize exposure to people, contamination of the environment, and loss of property.

2. Personnel roles, lines of authority and communications must be established.

Incident response procedures are designed to bring an out-of-control situation to a condition that will minimize the risk to workers and the public. Procedures directed towards containing the source of the risk are not meant to recover the situation, but rather to keep the situation from getting worse.

3. Emergency recognition and prevention during a response.

Employees participating as an emergency response team must be trained recognize health and safety hazards to protect themselves and others. This training should include:

- Methods used to minimize the risk from safety and health hazards.
- Selection and use of appropriate personnel protective equipment.
- Safe use of control equipment.
- Safe operating procedures to be used at the incident scene.
- Techniques of coordination with other employees to minimize risks.
- Appropriate response to overexposures from radiation, health hazards, or injury.
- Recognition of subsequent symptoms that may result from overexposures.

4. Keep safe distances and places of refuge from an incident.

When an evacuation is announced, employees are to stop working and go to the nearest available exit. Employees must leave the facility and report to the designated assembly area for accountability. The assembly area should be at a safe distance from possible radiation exposure.

5. Site security and control during the response.

Site security and control are the methods for controlling activities on the site, determining the hot, warm, and cold zones, controlling site access and traffic. This is a management responsibility that is often designated to security personnel, Radiation Safety personnel and supervisors. Hot, warm and cold zones are buffer control areas that are based on exposure or contamination levels. A cold zone is an area where no exposure or contamination is expected. Warm and hot zones are areas specified by exposure or contamination levels that require different levels of personnel protective equipment.

6. Follow evacuation routes and procedures.

Evacuation route maps should be posted throughout the facility.

3. Decontamination during the response to the incident.

A specific decontamination procedure must be developed, communicated to workers, and implemented before any worker or equipment may enter areas during an emergency response where the potential for exposure to radioactive materials or other hazardous substances exists. Decontamination must be performed in geographical areas that will minimize the exposure of uncontaminated employees or equipment (i.e., upwind and upgrade).

Workers or equipment are not allowed to enter the cold zone without going through decontamination first. Decontamination of workers must also be conducted prior to the removal of personal protective equipment. Decontamination should be monitored by Radiation Safety Personnel to determine the effectiveness and minimize exposure to the individual. If such procedures are found to be ineffective, appropriate steps are then taken to correct any deficiencies.

8. Provide emergency medical treatment and first aid.

The plan must contain directions to the nearest emergency medical facility, and an inventory, quantity, and location of emergency medical equipment within the facility.

9. Follow the emergency alerting and response procedures.

The response shall follow an orderly and comprehensive set of procedures that deal with specific incidents (i.e., radioactive material spill, chemical spill, contaminated worker, earthquake or other unpredicted natural disaster, leaking container and toxic gas leak.).

10. Critique of response and the follow-up procedures.

The plan should be reviewed periodically and, as necessary, be amended to keep it current with new or changing site conditions or information.

11. Selection of Personal Protective Equipment (PPE) and emergency equipment.

PPE is to be selected and used which will protect employees from the hazards that are likely to occur.

Section 9. Internal Control

LEARNING OBJECTIVES:

IDENTIFY two individuals identified by name on a radioactive material license.
IDENTIFY who approves the purchase of radioactive materials.
IDENTIFY why incoming packages are monitored upon arrival.
IDENTIFY what must be verified and why when transferring radioactive material to another facility.
STATE the whole-body exposure limits for a pregnant radiation worker.
IDENTIFY the purpose of an accurate inventory.
IDENTIFY general procedures for working with radionuclides in the laboratory.
SELECT a laboratory classification based upon the hazard guide.

INTRODUCTION

In an effort to minimize exposures to staff, visitors, and the environment in accordance with established regulations and industry guides of internal controls have been implemented. These controls enable users to maintain control on the radiation sources and minimize the regulatory impact.

A. PERMISSION TO USE RADIONUCLIDES

The use of radionuclides requires authorization from the Radiation Safety Officer and the Radiation Safety Committee when a committee is identified under the facility license. In general, an application is submitted to the Radiation Safety Officer who will review it for completeness. The Radiation Safety Officer will submit the application with recommendations to the Radiation Safety Committee for approval or denial with his/her recommendations. Persons who are granted this permission are designated as "Principal Users". Only individuals designated as "Principal Users" or working under the direct supervision of a Principal User are permitted to possess or use radionuclides. Each Principal User completes a "Statement of Training and Experience" with each application.

Permission to use radionuclides may be withdrawn for reasons including, but not limited to dosimetry, bioassay results indicating exposure at or near maximum permissible levels, or excessive levels of contamination on uncontrolled surfaces. In such an event, an investigation will be conducted, and the Principal User will be required to furnish an explanation of the incident and action taken to prevent recurrence.

B. License

No person shall manufacture, produce, transfer, receive, acquire, own, possess, or use byproduct material except as authorized in a specific or general license issued to Title 10, Code of Federal Regulations (10 CFR).

- Licensing agencies

The licensing authority for the general public falls under the Nuclear Regulatory Commission (NRC). NRC is responsible for licensing and regulating nuclear facilities and materials for conducting research in support of the licensing and regulatory process, as mandated by the Atomic Energy Act of 1954. These responsibilities include protecting public health and safety, protecting the environment, protecting and safeguarding nuclear materials and nuclear power plants in the interest of national security, and assuring conformity with antitrust laws. The Department of Defense obtains its licensing from the NRC, however, the Department of Energy does not. They regulate their own facilities.

When a state elects to maintain control of the radioactive materials within its borders it develops regulations and enforcement that is equal to, compatible with or exceeds the controls imposed by NRC. Once this has been agreed upon with NRC, the state becomes an "agreement state." Licensing for the state facilities and private industry then obtain they're licensing from the state. Federal facilities within an agreement state continue to obtain their license from NRC.

- License types
  There are several types of licenses authorized by regulatory authorities. The list below will provide some idea as to the complexity.

Exempt quantities
These are very low amounts of radioactive materials. The activity levels must be equal to or below the limits identified in 10 CFR, Schedule A.

General license
A manufacturer maintains this type of license to manufacture and distribute products that may be distributed to the general public. An example would smoke detectors.

Specific license of limited scope
This is routinely issued to an individual for a sealed source or device containing radioactive material. An example would be a set of sealed sources for calibrating a piece of equipment.

Specific license of broad scope (A, B or C)
The applicant must satisfy the general requirements specified in 10 CFR, Part 30. The applicant has engaged in a reasonable number of activities involving the use of byproduct material; and has established administrative controls and provisions relating to organization and management, procedures, record keeping, material control, and accounting management review that are necessary to assure safe operations.

Type "A" is the establishment of a radiation safety committee, appointment of a radiation safety officer (who is qualified by training and experience in radiation protection), establishment of appropriate administrative procedures to assure control of procurement and use of byproduct material, completion of safety evaluations of proposed uses of byproduct material that take into consideration such matters as the adequacy of facilities and equipment, training and experience of the user, and the operating or handling procedures.

Type "B" is a smaller program than a Type "A" and may not require a committee. The radiation safety officer is required.

Type "C" is a smaller program than a Type "B" and may not require a full time radiation safety officer.

All three types require the use of the radioactive materials under the direct supervision of an individual who has training and experience with the material. The supervisor should have a college degree at the bachelor level or above, or equivalent training and experience, in the physical or biological sciences or engineering. They should have at least 40 hours of training and experience in the safe handling of radioactive materials, and in the characteristics of ionizing radiation, units of radiation dose and quantities, radiation detection instrumentation, and biological hazards of exposure to radiation appropriate to the type and forms of by product material to be used; and has established administrative controls and provisions relating to procurement of byproduct materials.

Registration of sources
Specific sources (i.e., 3H Exit signs, x-ray tubes, etc.) must be registered within the various regulatory authorities. These sources have regulatory support that governs the use and location. An example would be compliance testing of diagnostic x-ray systems to protect the worker and the public. NRC does not regulate the x-ray sources, however most agreement states do for the sources within their borders. Other regulatory agencies regulate the x-ray sources for federal facilities.

The regulatory authority issues a radioactive material license. The application has to be reviewed and determined to be complete and acceptable by the regulatory agency. Various individual is identified on the license (i.e., the Radiation Safety Officer, the Chairman of the Radiation Safety Committee and the senior administrator of the institution). The Radioactive Material License Application must be signed by the Chief Executive Officer (President) before it is submitted the regulatory agency. The application is identified within the license when issued by the regulatory agency. Commitments made in the application become a part of the license and enforced as a contract with the regulatory agency. The individuals identified (by name) on the license and application will be (personally) accountable for the Radiation Safety Program.

Items identified on the license include the expiration date and a list of sources authorized. This includes the nuclide, physical form (sealed or unsealed), possession limits and locations of use or storage. Changes to the license requires amendments be submitted. The changes are not authorized until the license has been amended by the regulatory agency.

C. ORDERING RADIONUCLIDES FROM COMMERCIAL VENDORS

To purchase radionuclides, a requester will have to submit information on the Principal User, the isotope requested, the vendor, the order number and the amount. The Radiation Safety Officer or a designee will review the request against established limits for the Principal User, and the facility license inventory against the license limits. Once approved by the Radiation Safety Officer, the material may be ordered.

D. HANDLING INCOMING RADIOACTIVE MATERIAL

All incoming radionuclides are delivered to the Radiation Safety Officer or Radiation Safety Assistant before they are delivered to the requester. If the Radiation Safety Officer or Assistant is not available, the package will be stored in a controlled area with appropriate shielding prior to inspection. Incoming packages will be tested for external radiation with a survey meter and inspected visually for damage with might indicate possible leakage. A wipe test will be carried out on the package and properly assayed. The package will then be opened, and the innermost container examined for damage and wipe tested. If no contamination is apparent, it may be provided to the Principal User.

A wipe test is a sample made for the purpose of determining the presence of removable radioactive contamination on a surface. It is done by wiping, with slight pressure, a piece of soft filter paper over a representative type of surface area. The sample is analyzed in a radiation counting system appropriate for the type of radioactivity expected on the sample.

Under circumstances, where the nature of the radioisotope dictates that the user will require special services or instructions, the Radiation Safety Officer keeps the radioisotope until time of use. The Radiation Safety Officer then delivers the isotope and supervises the operation, provides special instructions and performs radiation monitoring as needed.

E. TRANSFER OF RADIONUCLIDES

Radioactive material license allows a Principal User to make the following transfers:

- Transfer radioactive materials to persons outside the facility who are specifically licensed by the US Nuclear Regulatory commission or a State Licensing authority to receive the radioactive materials.
- All outgoing radioactive materials must be processed through the Radiation Safety officer.

This will ensure that (first), the recipient is properly licensed, and (second), the radioactive material is properly packaged and meets all appropriate shipping and labeling regulations.

If transfer of radioactive materials to another authorized Principal User is to be done, the recipient must be authorized for the specific radioisotope being transferred for the appropriate quantities. The sender will notify the Radiation Safety Officer in writing of said transfer.

F. RADIOISOTOPE INVENTORY

Periodically all radioactive material in the possession of each Principal User will be inventoried, indicating the new total millicurie amount of each radioisotope. This physical data is compiled and summarized by the Radiation Safety Officer. This inventory data (as well as the radioisotope ordering system) ensures that the total radioisotope quantities do not exceed those authorized by the license.

Exempt quantities do not fall under these controls unless the facility has a Radioactive Material License. Then they must be accounted for as all other sources. When 10 or more exempt sources are acquired at a site or organization a license is then required.

G. DISPOSAL OF RADIOACTIVE WASTE MATERIALS

Regulations permit disposal of radioactive waste. It typically is handled by transference to a person holding a specific license to receive the radioactive waste (vendor). The facility does not lose liability for the waste after it has been transferred to this vendor. The facility continues its liability, even after it has been received at the disposal site.

Each facility will develop internal procedures for disposing of radioactive waste from laboratory facilities. The waste must be segregated and packaged according to specific regulations. Internal procedures are normally designed to enable the support staff to package waste according to these regulations.

H. PRENATAL RADIATION POLICY

The US Nuclear Regulatory Commission states that the whole-body exposure during the term of pregnancy (of the mother) be kept below 0.5 rem (0.005 Gray) for the entire gestation period and no more than 0.05 rem (0.5 mGy) in any single month. An information package on the risks of radiation exposure should be provided to all employees who may become pregnant. Pregnant employees are encouraged to take all possible steps to minimize their exposure to penetrating radiation.

I. LABORATORY PROCEDURE WITH RADIONUCLIDES

Specific laboratory handling and operating procedures for radioactive materials will vary with the particular radionuclides, quantity, and chemical form. However, some general laboratory responsibilities and rules are presented below for use by the Radiation User (Radiation Worker) as a guideline for the safe handling of radioactive materials:

- Disposable gloves, safety glasses and a lab coat must be used whenever handling, pippetting, or dispensing radioactive solutions.
- Keep exposure to radiation as low as reasonably achievable (ALARA), and specifically below the regulatory exposure limits. Most licensees have a regulatory commitment to maintain exposures below a specific limit. This limit is enforceable during regulatory inspections.
- Wear the prescribed dosimeters while working with radioactive material.
- NEVER pipette radioactive substances by mouth.
- ABSOLUTELY NO eating, drinking, smoking, applying cosmetics, or storing of food or beverages is permitted in areas controlled for the use of radionuclides.
- Use disposable plastic-backed absorbent sheets on all laboratory benches where radionuclides are used. Change the sheets frequently, and whenever they are contaminated.
- Use disposable glass or plastic-ware whenever practical when working with radionuclides. Any reusable lab-ware must be thoroughly decontaminated prior to being sent to central glass washing area.
- Use a survey meter during and after all radioisotope operations to follow the progress of radioactive material and to identify contamination. H-3 cannot be monitored in this manner and a wipe test should be performed after each use. C-14 and S-35 are difficult to monitor with a survey meter. Therefore, a wipe test may be necessary when working with microcurie amounts.
- Radioisotope work should be done in a certified fume hood whenever possible. This is due to the possibility of airborne contamination (evaporation, flaking, dust, or aerosol formation).
- Use protective barriers and other shields whenever possible.
- All stored radioactive materials must be labeled with the radionuclide, quantity, date, and words “Caution, Radioactive Material”, and the radiation caution symbol. When appropriate, include the user’s name.
- Stored radionuclides must be secured from unauthorized use.
- Notify the Radiation Safety Officer immediately of all spills.
- A radiological cleanup must be performed after each major operation that involves radioactive materials. All lab areas, equipment, glassware, etc. should be monitored and decontaminated.

- Survey hands, shoes, and body for radioactivity and remove all loose contamination before leaving the laboratory for any reason.
- All radioactive liquids must be stored and transported in double containment to minimize the threat of spills. Trays sufficiently deep to contain the entire volume that could be spilled make good secondary containment for bags, bottles, or vials of radioactive liquid.
- Maintain good personal hygiene:
  - Keep fingernails short and clean.
  - Do not work with radioactive materials if there is a break in the skin below the wrist.
  - Wash hands and arms thoroughly before handling any object that goes to the mouth, nose or eyes.
  - It is strongly recommended that open-toed shoes or shorts not be worn in the radioisotope laboratory.
- Containment control, distance from the radiation source, shielding and the minimizing time near the radiation source are the best tools for limiting radiation exposure.

J. RADIATION SAFETY MANUAL

Most licensees must maintain some type of Radiation Safety Manual. This manual should be reviewed as a part of training. In general, the Radiation Safety Manual contains information about the Radiation Safety Program vital to controlling the radiation sources and minimizing exposures. In addition, it is designed to minimize the regulatory impact and provide flexibility in the administration of a good Radiation Safety Program.

K. TRAINING MANAGEMENT PLAN

The training program should reflect the requirements identified in federal, state and international regulations and guidelines. Generally training includes initial and refresher training.

L. LABORATORY CLASSIFICATION

Operations involving radioactive material are designed, equipped and conducted to provide the maximum practicable protection of personnel and the surrounding environment against the hazards of ionizing radiation. The protective measures selected take into account the nature of the operations, the radionuclides involved, and the quantities that will be used.

1. PLAN

Operations with radionuclides planned by groups that do not have the proper facilities must be transferred to approve work areas. The selection of workplaces is based on the relative hazard of the manipulations, on the quantity, and on the radiotoxicity of the radionuclides involved. The relative hazard of an operation is determined by an evaluation of the following factors:

- The isotope to be used.
- The chemical form of the isotope.
- The critical organ and the most likely route of deposition for any isotope.
- The nature of the operation to be performed.
- The quantity of isotope that will be used.
- The experience of the user.

2. GUIDE FOR SELECTING WORKPLACES

The following method can be used as a guide for workplace selection. Operations involving high and very highly radiotoxic materials should always be referred to the RSO for final evaluation before proceeding with the operations.

Use the following equation to obtain a guide to the type of workplace required:

H = QTUE Where H = Hazard guide value

Q = Quantity of radionuclide (in μCi)

T = Toxicity factor

U = Use factor

E = Experience

After the hazard guide value is determined, Table 9.1 will indicate the type of workplace required. Note: This equation is only a guide and may not reflect the real requirements of a particular operation. In all cases, the RSO must be contacted for final review and approval. Frequently the H value will dictate the frequency of surveys required by the laboratory staff. As an example: Type III may require daily surveys, Type II may require weekly surveys and Type I may require monthly surveys.

Table 9.1 - Workplace versus Hazard Guide

Hazard Guide Value, H	**Workplace Required**
≤ 100	Type I
100 - 1000	Type II

≥ 1000	Type III

Table 9.2, below, provides a classification of radionuclides according to toxicity (toxicity factor - T).

Table 9.2 - Toxicity values

Very High Radiotoxicity (Group 1) (Relative Toxicity Factor = 100)

^{210}Pb	^{228}Ra	^{229}Th	^{232}U	^{236}Pu	^{241}Pu	^{243}Am	^{244}Cm	^{248}Cm	^{251}Cf
^{210}Po	^{227}Ac	^{230}Th	^{233}U	^{238}Pu	^{242}Pu	^{240}Cm	^{245}Cm	^{248}Cf	^{252}Cf
^{223}Ra	^{227}Th	^{231}Pa	^{234}U	^{239}Pu	^{241}Am	^{242}Cm	^{246}Cm	^{249}Cf	^{254}Cf
^{225}Ra	^{228}Th	^{230}U	^{237}Np	^{240}Pu	^{242m}Am	^{243}Cm	^{247}Cm	^{250}Cf	^{254}Es
^{226}Ra									

High Radiotoxicity (Group 1) (Relative Toxicity Factor = 10)

^{22}Na	^{90}Sr	^{110m}Ag	^{124}I	^{140}Ba	^{170}Tm	^{212}Pb	^{228}Ac	^{244}Pu	^{253}Cf
^{36}Cl	^{91}Y	^{115m}Cd	^{125}I	^{144}Ce	^{181}Hf	^{207}Bi	^{232}Th	^{242}Am	^{253}Es
^{45}Ca	^{93}Zr	^{114m}In	^{126}I	^{152}Eu	^{182}Ta	^{210}Bi	Th-nat[b]	^{241}Cm	^{254m}Es
^{46}Sc	^{94}Nb	^{124}Sb	^{131}I	^{154}Eu	^{192}Ir	^{211}At	^{230}Pa	^{249}Bk	^{255}Fm
^{60}Co	^{106}Ru	^{125}Sb	^{134}Cs	^{160}Tb	^{204}Tl	^{224}Ra	^{236}U	^{246}Cf	^{256}Fm

Moderate Radiotoxicity (Group 1) (Relative Toxicity Factor = 1)

^{7}Be	^{52}Fe	^{82}Br	^{97}Zr	^{105}Ag	^{134}Te	^{143}Ce	^{171}Tm	^{198}Au	^{237}U
^{14}C	^{55}Fe	^{74}Kr	^{90}Nb	^{111}Ag	^{120}I	^{142}Pr	^{175}Yb	^{199}Au	^{240}U
^{18}F	^{59}Fe	^{77}Kr	^{93m}Nb	^{109}Cd	^{123}I	^{143}Pr	^{177}Lu	^{197}Hg	^{240}Np
^{24}Na	^{55}Co	^{87}Kr	^{95}Nb	^{115}Cd	^{130}I	^{147}Nd	^{181}W	^{197m}Hg	^{239}Np
^{31}Si	^{56}Co	^{88}Kr	^{96}Nb	^{115m}In	^{132m}I	^{149}Nd	^{185}W	^{203}Hg	^{234}Pu
^{32}P	^{57}Co	^{86}Rb	^{90}Mo	^{113}Sn	^{133}I	^{147}Pm	^{187}W	^{200}Tl	^{237}Pu

^{33}P	^{58}Co	^{83}Sr	^{93}Mo	^{125}Sn	^{135}I	^{149}Pm	^{183}Re	^{201}Tl	^{245}Pu
^{35}S	^{63}Ni	^{85}Sr	^{99}Mo	^{122}Sb	^{135}Xe	^{151}Sm	^{186}Re	^{202}Tl	^{238}Am
^{38}Cl	^{65}Ni	^{89}Sr	^{96}Tc	^{121}Te	^{132}Cs	^{153}Sm	^{188}Re	^{203}Pb	^{240}Am
^{41}Ar	^{65}Cu	^{91}Sr	^{97m}Tc	^{121m}Te	^{136}Cs	^{152m}Eu	^{185}Os	^{206}Bi	^{244m}Am
^{42}K	^{65}Zn	^{92}Sr	^{97}Tc	^{123m}Te	^{137}Cs	^{155}Eu	^{191}Os	^{212}Bi	^{244}Am
^{43}K	^{69m}Zn	^{90}Y	^{99}Tc	^{125m}Te	^{131}Ba	^{153}Gd	^{193}Os	^{220}Rn	^{238}Cm
^{47}Ca	^{72}Ga	^{92}Y	^{97}Ru	^{127m}Te	^{140}La	^{159}Gd	^{190}Ir	^{222}Rn	^{250}Bk
^{48}Sc	^{73}As	^{93}Y	^{103}Ru	^{129m}Te	^{134}Ce	^{165}Dy	^{194}Ir	^{226}Th	^{244}Cf
^{48}Sc	^{74}As	^{86}Zr	^{105}Ru	^{131}Te	^{135}Ce	^{166}Dy	^{191}Pt	^{231}Th	^{254}Fm
^{48}V	^{76}As	^{88}Zr	^{105}Rh	^{131m}Te	^{137m}Ce	^{166}Ho	^{193}Pt	^{234}Th	
^{51}Cr	^{77}As	^{89}Zr	^{103}Pd	^{132}Te	^{139}Ce	^{169}Er	^{197}Pt	^{233}Pa	
^{52}Mn	^{75}Se	^{95}Zr	^{109}Pd	^{133m}Te	^{141}Ce	^{171}Er	^{196}Au	^{231}U	
^{54}Mn									

Low Radiotoxicity (Group 1) (Relative Toxicity Factor = 0.1)

^{3}H	^{60m}Co	^{81}Kr	^{91m}Y	^{99m}Tc	^{120m}I	^{127}Cs	^{138}Cs	^{207}Po	^{243}Pu
^{15}O	^{61}Co	^{83m}Kr	^{88}Nb	^{103m}Rh	^{121}I	^{129}Cs	^{137}Ce	^{227}Ra	^{237}Am
^{37}Ar	^{62m}Co	^{85m}Kr	^{89}Nb	^{113m}In	^{128}I	^{130}Cs	^{191m}Os	^{235}U	^{239}Am
^{51}Mn	^{59}Ni	^{85}Kr	^{97}Nb	^{116}Te	^{129}I	^{131}Cs	^{193m}Pt	^{238}U	^{245}Am
^{52m}Mn	^{69}Zn	^{80}Sr	^{98}Nb	^{123}Te	^{134}I	^{134m}Cs	^{197m}Pt	^{239}U	^{246m}Am
^{53}Mn	^{71}Ge	^{81}Sr	^{93m}Mo	^{127}Te	^{131m}Xe	^{135}Cs	^{203}Po	U-nat	^{246}Am
^{56}Mn	^{76}Kr	^{85m}Sr	^{101}Mo	^{129}Te	^{133}Xe	^{135m}Cs	^{205}Po	^{350}Pu	^{249}Cm
^{58m}Co	^{79}Kr	^{87m}Sr	^{96m}Tc	^{133}Te	^{125}Cs				

[a] Based on the classification published in the Official Journal of the European Communities, No. L246, vo.. 23; Luxembourg; 17 Sep. 1980.

[b] One becquerel of natural thorium corresponds to 1 alpha disintegration per second (dps)(0.5 dps of ^{232}Th and 1.85 x 10^{10} dps of ^{228}Th).

The activity should be limited according to the various types of workplace. Table 9.3 provides the recommended limits of activity for use in various types of workplaces.

Table 9.3 - Activity Limits by Workplace Types

Radionuclide Group	Type I	Type II	Type III
	------Type of workplace------		
Very high	500 K Bq or less	500 K Bq - 500 M Bq	500 M Bq or more
High	5 K Bq or less	5 M Bq - 5 G Bq	5 G Bq or more
Moderate	50 M Bq or less	50 M Bq - 50 Bq	50 G Bq or more
Low	500 M Bq or less	500 M Bq - 500 G Bq	500 G Bq or more

3. USE FACTOR

The use factor is a description of the nature of the operations where unsealed radioactive materials are handled or stored. Table 9.4 provides a list of the modifying use factors, which should be applied:

Table 9.4 - Use Factor

Type of Operation	Use Factor, U
Storage	0.01
Very simple, wet	0.1
Diluting stock solutions	
Washing precipitates	
Normal	1
No production of dry material	
No vigorous chemical reactions	
Precipitation	
Filtration or centrifuging	
Solvent extraction	
Chromatography	
Pipetting or titration	
Simple, dry	10
Fusion reactions	
Fluorination	
Transfer of dry precipitates	
Complex, wet	10

Distillation
Sampling and transfer
Evaporation to dryness

Dry and dusty 100

Machine or hand crushing
Machining or sawing
Sieving
Mixing

4. EXPERIENCE AND TRAINING

The evaluation of the training and experience is subjective. This is based upon answering general questions. The range of values for Experience is from 1 to 100.

- Does the requestor have experience with the radionuclide?
- Does the requestor have experience with the procedure?
- Are the procedures well defined and minimizes risk where possible?
- Does the requestor have a good history of working with this radionuclide?
- Does the requestor have any experience with this quantity of radionuclides?
- Will the requestor be working under the direction of an experienced individual for this procedure?

5. Quantity of radionuclide

The quantity used during a period of (monitoring) time. The units are in microcuries (μCi). How much per experiment times the number of experiments during the monitoring period. Most often, the monitoring period is monthly. Dosimetric devices (film badges) are commonly changed monthly.

6. EXAMPLES

a. It is desired to store 14 μCi of ^{90}Sr
From the factor tables:

T = 10
U = 0.01
Q = 14
E = 1 (assuming the user is fully trained and has experience)

Then H = QTUE = 14 X 10 X 0.01 X 1 = 1.4

This value indicates a Type I Workplace.

b. It is desired to distillations and evaporation of 0.25 μCi of ^{33}P
From the factor tables:

T = 1
U = 10
Q = 0.25
E = 1 (assuming the user is fully trained and has experience)

Then H = QTUE = 0.25 X 1 X 10 X 1 = 2.5

This value indicates a Type I Workplace.

c. It is desired to filter and centrifuging 25 μCi of ^{14}C. The researcher has no experience with this radionuclide but has significant experience with similar radionuclides (^{35}S). The procedures are new and never tested before. The procedure is well planned and appears to minimize risk.

From the factor tables:

T = 1
U = 1
Q = 25
E = 10 (assuming the user has some experience and well-defined procedures)

Then H = QTUE = 25 X 1 X 1 X 10 = 250

This value indicates a Type II Workplace.

6. CLASSIFICATION OF WORKPLACES

The classification of workplaces stated below serves to select areas and equipment suitable for safe operations with the radioactive material to be used. Work places of all three types should be reserved exclusively for work with radioactive substances and isolated from other workplaces as far as is practicable. They should be subject to classification according to the potential risks involved. Normally areas where radioactive substances are used will be classified as controlled areas. Areas where workers are not likely to receive more than three tenths of the dose limits may be either included in a controlled area or defined as supervised areas, if this is duly justified and considered more convenient.

a. **Type I** (type C) workplaces are used only for low-hazard operations. The design, construction and equipment of the workplace should be similar to those of a good quality, modern chemical laboratory. The minimum requirements for such workplaces are:
   (1) The ventilation shall provide at least six air changes per hour.
   (2) The work surfaces shall be smooth and impermeable.
   (3) Personnel shall wear aprons or laboratory coats.
   (4) Sources of radiation shall be stored in metal cabinets.
   (5) A periodic monitoring program shall be maintained to detect any contamination of surfaces.

b. **Type II** (type B) workplaces are used for operations of moderate or low hazard. The workplace should be specifically designed, constructed and equipped for work with radionuclides. The minimum requirements for such workplaces are:

(1) Operations shall be carried out in hoods with minimum exhaust velocity of 125 feet per minute at any point of the hood opening. High efficiency filters may be required on the hood exhaust if the Health Physicist feels they are warranted.
(2) The walls and floors shall be smooth and be protected with impermeable coverings.
(3) The coverings of work surfaces shall be smooth, impermeable, and adapted to the type of operations.
(4) Personnel shall wear laboratory coats and waterproof gloves.
(5) Sources of radiation shall be stored in a hood or in a glove box, or other approved container.
(6) A monitoring program shall be maintained as appropriate to detect external radiation, surface contamination, and airborne radioactivity.
(7) Special receptacles shall be provided for separate collection of solid and liquid residues generated in the workplace.
(8) Facilities for washing hands should be foot or elbow operated.
(9) A special room or location should be provided for storing radioactive substances.

c. **Type III** (type A) workplaces are used for operations classed as high hazard. This workplace should be specifically designed, constructed and equipped for handling large quantities of radioactive material in accordance with the specifications and requirements laid down by the competent authority. These workplaces must be isolated from other working areas. The minimum requirements for such workplaces are:

(1) Operations shall be carried out in gloved boxes equipped with negative-pressure ventilation and high-efficiency filters. At least three stages of HEPA filtration are required for glove boxes and a fire protection system should be provided for the filters. Other protective devices shall be included commensurate with the degree of hazard associated with the operations, namely, shielding, remote handling devices, air locks, bag-out ports, etc.
(2) The walls, ceilings, and floors shall be provided with impermeable coverings.
(3) The coverings of work surfaces shall be smooth, impermeable, and adapted to the type of operation.
(4) The atmosphere in workrooms shall be maintained at negative pressure with respect to other parts of the building.
(5) Room exhaust shall be filtered through high-efficiency filters. At least two stages of HEPA filtration are required for room exhaust and a filter fire protection system shall be provided.
(6) Access to the workplace shall be limited to those persons actually needed to perform the operations.
(7) Protective clothing such as lab coats and gloves and protective equipment such as respirators will be employed as specified by the Health Physicist.

(8) Sources of radiation shall be stored in gloved boxes, source pits, water pools, or other devices commensurate with the degree of hazard and the nature of the material.
(9) A continuous monitoring program shall be maintained to detect atmospheric contamination, external radiation, and surface contamination.
(10) Special receptacles shall be provided for separate collection of solid and liquid residues generated during operations.
(11) Alarm devices shall be installed to warn personnel of external radiation or airborne contamination exceeding permissible levels.
(12) Radioactive substances should be stored only in a special room equipped with suitable shielding and ventilation, and in accordance with the provisions as regards waste storage.

8. PROCEDURAL CONTROL

All operations involving actual or potential exposure to ionizing radiation shall be under the direct supervision of competent technical personnel who are qualified by training and experience to deal effectively with technical and safety problems, which may arise. Qualifications are determined, reviewed and approved by the Radiation Safety Committee. The qualifications for an "Authorized User" (AU) are as follows:

a. A faculty or staff member of the University with the appropriate education.
b. A college degree in physical or biological sciences, engineering or a technician with a demonstrated radioactive materials usage background.
c. A minimum of 40 hours of training in radiation safety. This requirement may be satisfied by the following:
   (1) Radiation Safety Course (Health Physics), a formal course at the University consisting of 40 hours of lecture in Health Physics including practical exercises in a laboratory environment.
   (2) Equivalent training of the above at a different institution.
   (3) Prior training and experience in handling radioactive materials commensurate with the proposed use.
a. A facility safety review.

All students, faculty and staff are required to complete the Health Physics course, Radiation safety or an equivalent course whenever the amount of radioactive material (whether as sealed or unsealed source material) to which they will be exposed is of such a level as to require a specific license. The following are exceptions:

a. A student enrolled in a regular University class, which uses radioactive materials or radiation producing devices in procedures approved by the Health Physics Committee.
b. The instructor of the course is an "Authorized User" and has a current "Radiation Use Authorization".
c. The maximum amount of activity used in the course is available under a general license as stated in Title 17, Schedule A; Exempt Quantities.
d. A supplement to this procedure outlining specific safety criteria for the operation has been written and an evaluation has been made by the RSO as to the operator's

understanding and demonstrated use of all safety criteria.

No "User " shall release or cause to be released into air or water, in any uncontrolled area, any concentration of radioactive material which could, averaged over a 24 hour period, exceed the limits specified in Appendix Vi, Table II. The concentration limits shall apply at the boundary of the controlled area.
Film badges will be used to measure individual exposure to ionizing radiation.

Section 10. RADIOLOGICAL CONTAMINATION

LEARNING OBJECTIVES:

DISTINGUISH between ionizing radiation and radioactive contamination.
DEFINE fixed, removable and airborne contamination.
IDENTIFY the units used to measure radioactive contamination.
IDENTIFY causes of radioactive contamination.
STATE the appropriate response to indicators of potential area contamination or personnel contamination alarms.
IDENTIFY indicators of possible area contamination.

INTRODUCTION

This section is designed to inform the worker about sources of radioactive contamination encountered in the laboratory environment. Contamination control is one of the most important aspects of radiological protection. Using proper contamination control practices will help ensure a safe working environment.

Your will be exposed to radiation if you are near a radioactive source. The longer you stay or the closer you get to the source, the greater your radiation does. If radioactive materials get on you, or worse, inside you, then you are considered contaminated with radioactive material. You are also being continuously exposed to the radiation by the radioactive material that has contaminated you until the contamination has been removed.

A. COMPARISON OF RADIATION AND RADIOACTIVE CONTAMINATION

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

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

Radiation is energy. Contamination is material. See figure 10.1.

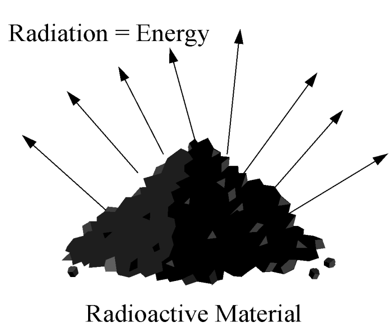


FIGURE 10.1 - RADIATION VERSUS RADIOACTIVE MATERIAL

B. TYPES OF CONTAMINATION

Radioactive contamination can be fixed, removable or airborne.

1. Fixed contamination

Fixed contamination cannot be readily removed from surfaces. It cannot be removed by casual contact. It may be released when the surface is disturbed (buffing, grinding and using volatile liquids for cleaning). Over time it may "weep", leach or otherwise become loose or transferable. Fixed contamination should be marked and well identified for future decontamination. Knowing where the fixed contamination is located will help prevent others from being exposed.

2. Removable/transferable contamination

Removable or transferable contamination can readily be removed from surfaces. It may be transferred by casual contact, wiping, brushing or washing. This form of contamination presents a significant risk to workers and should be removed as soon as possible.

3. Airborne contamination

This is airborne radioactive material that is suspended in the air. Air movement across removable/transferable contamination could cause airborne contamination. Appreciable amounts of radioactive material that is airborne will require more advanced personal protective equipment such as respirators. Additional training and medical screening for such equipment is required.

C. UNITS OF RADIOACTIVE CONTAMINATION

Because radioactive contamination is radioactive material, the units are expressed in activity. When measuring the amount of radioactive contamination (material) on a surface (area) or contained within a specific space (volume), the units most commonly used are disintegrations per minute (dpm) or activity per volumetric measurement (i.e., μCi/ml or Bq/ml).

1. Direct reading

Contamination monitors measure radiation emitted by the radioactive material. The radiation may enter the detector <u>and</u> be counted as a single event. The units that are normally measured by the monitor (through the detector) are counts per minute (cpm).

2. Counts per minute (cpm) versus disintegrations per minute (dpm).

There is a direct relationship between the counts recorded and the actual activity (disintegrations) present. A multiplication factor is used to convert the cpm to dpm. This is called the efficiency.

cpm / dpm = efficiency

A more accurate equation uses the net counts (cpm – background)

(net cpm) / dpm = efficiency

3. Removable contamination

Measuring removable contamination is done by swiping or smearing the surface, and then counting the amount of activity that is lifted (removed) from the surface. A wipe test is the amount of activity over a 100 cm^2 surface area. A swipe test does not identify the total surface area, however, the units are presented as if they were a wipe test. A swipe test is general a screening method. A wipe test is a method to officially document activity on a surface and is used for specific (official) records.

4 Annual Limit of Intake (ALI)

This is the quantity of a single radionuclide that if inhaled or ingested in one year would irradiate a person, represented by reference man to the limiting value for control of the workplace. The Derived Air Concentration is the quantity obtained by dividing the ALI for any given radionuclide by the volume of air breathed by an average worker during a working year (2.4×10^3 m^3). The derivation of the ALI is based on known metabolic processes for the isotopes involved and reference man.

4. Derived Air Concentration (DAC)

The DAC is equal to the ALI divided by the volume of air breathed by the average worker during a working year (0.02 m^3/minute; 60 minute/hour; 2000 hours/year).

6. Reference Man

Reference Man defines the physiological makeup of an average man in terms of factors required for dose calculations and includes such items as: height and other dimensions, mass, and size and mass of organs. Reference Woman has also been defined but is less used by the Health Physics community.

D. CAUSES OF RADIOACTIVE CONTAMINATION

Radioactive material can be spread to unwanted locations. There are several sources and indicators of radioactive contamination.

1. Leaks or breaks in radioactive systems

Hot particles, which are small, sometimes microscopic pieces of radioactive material that are highly radioactive, they can cause a high, localized radiation dose in a short period of time if they remain in contact with skin/tissue. Hot particles may be present when contaminated systems leak, are opened or when machining, cutting, or grinding is performed on highly radioactive materials. These processes include:

- Opening radioactive systems without proper controls
- Airborne contamination depositing on surfaces
- Leaks or tears in radiological containers (barrels, plastic bags or boxes)
- Poor housekeeping in contaminated areas
- Excessive motion or movement in areas of higher contamination
- Sloppy work practices, such as cross-contamination of tools, equipment or workers

E. INDICATORS OF POSSIBLE AREA CONTAMINATION

1. Visual indicators:

- When leaks, spills, standing water are observed, there is a significant probability of contamination present.
- When dusty and hazy air is observed, airborne contamination could be present.
- Damaged radiological containers present a spill hazard.

2. Detection of contamination or elevated radiation levels:

- Spurious or unexplained personnel contamination
- Radioactivity observed in bioassay samples collected
- Higher than normal background during personnel contamination surveys
- Airborne monitor alarms

F. PRIMARY REASONS FOR CONTAMINATION CONTROL MEASURES

1. Protection of the worker

Measures to control radioactive contamination are implemented to protection workers:

- Minimizing the chance of inhalation or ingestion of radioactive/hazardous material.
- Eliminating or reducing external radiation dose rates.
- Reducing worker discomfort by minimizing the use of personal protective clothing and/or respirators.

2. Radioactive materials may enter the body by:

- Inhalation (the most common pathway)
- Cuts/wounds (concern with sharps) punctures
- Absorption (skin, mucous membranes, eyes)
- Ingestion (biting nails, applying makeup, eating, drinking, etc.)

3. Protection of the environment

Measures to control radioactive contamination are implemented to protect the environment by:

- Controlling the release of radioactivity in the environment

- Minimizing the amount of radioactive waste generated

4. Protection of the facility and programs

Measures to control radioactive contamination are implemented to protect facilities and programs by:

- Eliminating or minimizing the spread of contamination
- Preventing cross-contamination and the loss of experimental results
- Meeting regulatory requirements

G. CONTAMINATION CONTROL MEASURES

Contamination control measures should address:

Know the characteristics of radionuclides used.

Preparation of areas and materials that include:

- Marking, labeling, and posting of areas and materials.
- Personnel protective equipment; type, availability, and use.
- Storage and containment of radioactive/hazardous materials.

Good work practices that include:

- Special precautions for handling liquids.
- Special precautions for handling sharps.

Radioactive waste management to control contamination and cost are implemented.

Radiation monitoring (including interpretation of meter readings) during and at completion of the work is performed.

Decontamination of the personnel and equipment performed promptly.

Regulatory requirements that are imposed or implied are followed.

Training requirements necessary to control the material used is imposed.

Section 11. Commonly Used Radionuclides

LEARNING OBJECTIVES:

DEFINE how radionuclides are classified for toxic effects.
IDENTIFY the difference between the physical half-life, biological half-life and the effective biological half-life.
DEFINE what are the critical body organ and the method of personnel monitoring.
DEFINE how radioactive materials move through the body.

INTRODUCTION

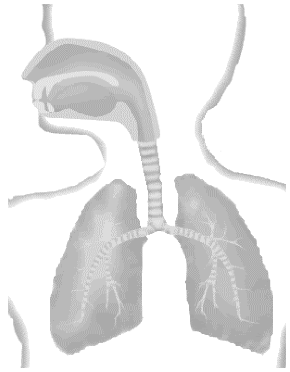
Each radioisotope has specific characteristics that are unique. These help define the hazards associated with the radioactive source. Understanding these characteristics will enable the worker to identify and take the appropriate protective measures to minimize exposure to ionizing radiation.

A. How Radioactive Materials Move Through the Body

Monitoring for internal contamination is very different then external monitor of exposures. There is no monitoring system that can be placed on or in the body to determine the activity of the radioactive material that is in the body or the dose received by the individual as a result of irradiation of tissues from the radioactive material. The method of assessment is based upon what happens to the radioactive material when it enters the body or what the body does with it.

It is important to know the normal metabolic processes within the body and how it applies to the radioactive materials. The body does not differentiate between an atom that is radioactive and one that is not. The body assumes that they are the same element. In terms of metabolic processes, the material is handled the same way. Once the material (element) enters to body its behavior is governed by the chemical form, its location in the body, and the body's need for that element.

B. Normal Metabolic Pathways



1. Inhale

Most of the material inhaled will be exhaled depending on the chemical. Some will be deposited in the lungs with eventual transfer to the GI tract or retained in the lungs. Some will be transported directly to other body fluids. Some will be transferred to the lymph nodes with eventual movement to the body fluids. The lymph nodes may also retain a small amount.

Once in the bodily fluids, the possibilities include the transfer to specific organ depending of the chemical need of that organ. Much may be filtered and eliminated by the kidneys and through the GI tract. Depending on the element it may also be removed from the body through the circulatory system (perspiration).

Insoluble particulates will be retained in the lung for a long or short time based on the particle size and density. A small amount will be swallowed and processed by the digestive tract when the body attempts to remove the material from the lungs. When this occurs, it is often found in the fecal waste.

Some of the soluble particulate will be eliminated from the lungs by exhalation. It is also dependent on the particle size and density. Some will be removed to the GI tract for elimination or to body fluids. The transfer to body fluids through the lymph nodes can be directly from the lungs. The lymph nodes will retain some of the material.

2. Ingested

Absorption by ingestion occurs poorly for elements not used by the body. It will pass straight through the body. It will pass through the stomach to the small intestine where transport of soluble materials to body fluids will occur. From there it will go to the organ of interest and/or be removed through normal biological elimination processes.

3. Absorbed

Many radioactive isotopes have been reported as absorbable through the skin. These isotopes include tritium (^3H), iodine, and some of the transuranics in an acidic form. These generally do not pose any considerable concern because of the relative percentages absorbed as opposed to entry through inhalation. The most important of these is tritium as water vapor (HTO). As much tritium existing as water vapor will be absorbed through the skin as will enter through inhalation. Once absorbed into the body, tritium exchanges freely with hydrogen and disperses throughout the body almost immediately. It then irradiates bodily tissue throughout the body.

4. Injected (wounds)

Material injected into the body will go directly to the body fluids and transport the same as if it were absorbed. This includes open sores and punctures of the skin or body.

C. RANGE

The energy of the radiation emitted determines the maximum range (penetration) of the radiation emitted. The range also depends upon the media it is traveling through. To penetrate the dead layers of the skin requires energies of 70 keV or more for beta emitters.

D. RADIOTOXICITY

Radionuclides are classified by their radiotoxicity by the International Atomic Energy Agency (IAEA). This is based on the element and the radiation expressed by the isotope and not a chemical compound.

E. PHYSICAL HALF-LIFE

The physical half-life is the statistical estimate of the time for one half of the radioactive material to decay to a lower energy state (commonly to a non-radioactive state). Each radioactive isotope has a distinctive decay rate that is not influenced by the physical process, including biological functions.

F. BIOLOGICAL HALF-LIFE

There are several biological elimination processes that are used by the body to eliminate materials from the body. These processes will reduce excessive amounts of material that the body does use. The biological half-life is the estimation time it takes for the body to eliminate one half of the initial material from the body by normal methods of elimination (assuming reference man is the individual of interest). Reference man is a hypothetical aggregation of human physical and physiological characteristics arrived at by international consensus. Researchers and public health workers to standardize results of the experiments use the characteristics. They also relate biological insult to a common base.

G. EFFECTIVE HALF-LIFE

The effective half-life is the time required for the amount of a radioactive element deposited in a living organism to be diminished 50 percent as a result of the combined action of radioactive decay and biological elimination. Elimination is the removal of material from the body via urine, feces, sweat or exhalation. Excretion usually refers to elimination via urine or feces.

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

H. Other Steps to Reduce the Dose

Once the presence of radioactive material in the body is known, there are steps that can be taken by medical personnel to increase the elimination rates (biological), thus will reduce the dose received as a result of the intake/uptake.

1. Blocking agents – A chemical that saturates the metabolic process in a specific tissue with the stable element and reduces uptake of the radioactive forms of the element.

2. Diluting agents – A compound that includes a stable form of the nuclide of concern. By introducing a large number of stable atoms, the statistical probability of the body incorporating radioactive atoms is reduced.

3. Mobilizing agents – A compound that increases the natural turnover process, thus releasing some forms of the radionuclides from the body tissues.

4. Chelating agents – A compound that acts on insoluble compounds to form a soluble complex ion that can then be removed through the kidneys. It acts directly with the radionuclide before it is absorbed.

5. Diuretics – These compounds increase the urinary excretion of sodium and water.

6. Lung lavage – This involves multiple flushing of the lungs with appropriate fluid to remove radioactive materials in the lungs.

I. CRITICAL ORGAN

The critical organ is that part of the body where the most effective dose equivalent is delivered. The body organ receiving a radionuclide or radiation dose that results in the greatest overall damage to the body. Effective dose equivalent is the sum of the products of the dose equivalent to the organ or tissue and the weighting factors applicable to each of the body organs or tissues that are irradiated.

J. MONITORING

The recommended personnel monitoring will provide useful information to determine the dose delivered.

K. ANNUAL LIMIT OF INTAKE (ALI)

The Annual Limit of Intake defines the amount of the radioisotope that will deliver the maximum dose to the critical organ according to regulatory standard (a regulatory overexposure, not observable biological damage). It is the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year.

L. SHIELDING

The recommended shielding is the amount of material suggested to reduce the dose rate. It is any material or obstruction that absorbs radiation and thus tends to protect personnel or materials from the effects of ionizing radiation.

TRITIUM (^3H)

Tritium is a low energy beta emitter and cannot be monitored directly with portable survey meters. Monitoring is performed by taking a survey (swipe) of the area and counting the swipe by liquid scintillation.

1. Maximum energy: 0.018 MeV (average energy is 0.006 MeV)
2. Maximum range in air: 0.25 inches (6 mm)
3. Maximum range in water: 6×10^{-3} mm
4. IAEA Radiotoxicity classification: (Low)
   Low hazard from 1to 25 mCi per item to 100 mCi possession

   Moderate hazard 25 mCi per item to 10 Ci possession
   High hazard when greater than 10 Ci
5. Physical half-life: 12.35 years
6. Effective half-life: 10 days
7. Critical Organ: whole body
8. Personnel Monitoring: Bioassay - urinalysis, NOT detected with a dosimeter (TLD or film badge
9. ALI : 80 mCi (3×10^9 Bq) tritiated water (the maximum amount of radioactive material which will deliver the dose to the critical organ of interest exceeding regulatory limits of a radiation worker during a working year)
10. Shielding: None (the penetration of the beta is extremely low)
11. Special considerations:

a. It cannot be monitored directly.

b. Many compounds readily penetrate gloves and the skin.

c. Bremsstrahlung may be a consideration for large quantities of tritium.

d. Tritiated DNA precursors are considered more toxic than tritiated water but are generally less volatile and do not present a significantly greater hazard.

CARBON -14 (^{14}C)

Carbon-14 is a low energy beta emitter that is about 10 times more energetic than tritium. C-14 may be detected with the proper radiation survey instrument and with proper care in conducting the survey.

1. Maximum energy: 0.156 MeV (the average energy is 0.052 MeV)
2. Maximum range in air: 9 inches (24 cm)
3. IAEA Radiotoxicity classification: (Medium-low)
   Medium-low from 0.1 to 10 mCi

   Moderate hazard from 10 mCi to 1.0 Ci

   High hazard above 1.0 Ci
4. Physical half-life: 5730 years
5. Effective half-life: 10 days
6. Critical Organ: Whole body and the body fat
7. Personnel Monitoring: Bioassay - urinalysis and/or breath measurements (CO_2), NOT detected with a dosimeter (TLD or film badges)
8. ALI: 2 Ci (7 x 10^{10} Bq) CO (monoxides) by inhalation

   200 mCi (7 x 10^{9} Bq) CO_2 (dioxides) by inhalation

   2 mCi (7 x 10^{7} Bq) for all other compounds
9. Shielding: 3 mm of Plexiglas but 1 cm required for rigidity
10. Special Considerations:

a. Detection of C-14 by radiation survey instruments requires special care due to the low efficiency of detection.

b. Some C-14 labeled compounds may penetrate gloves and skin.

c. Special caution should be observed when handling C-14 labeled halogenated acids.

SODIUM-22 (^{22}Na)

Sodium-22 is a positron emitter (positive beta particle/electron) and high-energy gamma emitter. It also emits an annihilation photon when the positive electron is annihilated with a negative electron, producing pure energy. Sodium-22 is detected with a thin end-window G-M probe, sodium-iodide scintillation counter or liquid scintillation detector.

1. Maximum energy:

   Maximum beta energy: 0.546 MeV (average energy 0.182 MeV)

   Gamma energy 1.275 MeV; annihilation photon: 0.511 MeV

2. Maximum range in air: 4.7 feet (1.4 m)
3. Unshielded dose rate from 1 mCi point source at 0.5 inches (1 cm): 11.8 rad/hr
4. IAEA Radiotoxicity Classification: High-medium;
5. Physical half-life: 950 days
6. Effective half-life: 10.9 days
7. Critical Organ:

   Whole body for intake of transportable compounds

   Lungs for inhalation; and Lower large intestine for ingestion

8. Personnel Monitoring: Dosimeter, finger rings, uptakes determined by urinalysis
9. ALI: 0.6 mCi (2 x 10^7 Bq) by inhalation, clearance in weeks

   0.4 mCi (1 x 10^7 Bq) by ingestion

10. Shielding: 6.5 mm of lead is the first half value layer (thickness of lead which will reduce the dose rate by one half).

    Multi-hundred mCi quantities need to be completely surrounded by beta shielding material to prevent the betas from escaping and creating a source of secondary annihilation radiation outside the shielding.

11. Special Considerations:

a. Near an unshielded Na-22 source, dose rates due to beta radiation can be much higher than dose rates due to gamma radiation.
b. Avoid direct eye exposure by interposing transparent shielding or indirect viewing.
c. Avoid skin dose by indirect handling.

PHOSPHORUS-32 (^{32}P)

Phosphorus-32 is a high-energy beta emitter that may create a whole body, skin and eye hazard. Most common means of detection is with a thin-window probe or liquid scintillation.

1. Maximum energy: 1.71 MeV (the average energy is 0.570 MeV)
2. Maximum range in air: 19 feet (6 m)
3. Maximum range in tissue: 8 mm

4 IAEA Radiotoxicity Classification: (Medium-low)

Low hazard from 0.01 to 1 mCi

Moderate hazard from 1 to 100 mCi

High hazard above 100 mCi

5. Physical half-life: 14.29 days
6. Effective half-life: 13.5 days
7. Critical Organ:

a. Bone - for transportable compounds

b. The lung and lower large intestine are critical organs for inhalation and ingestion.

8. Personnel Monitoring: Dosimeter for the external exposures and urinalysis for uptakes
9. ALI: 4 mCi (1×10^7 Bq) by inhalation, clearance in weeks

   4 mCi (1×10^7 Bq) by ingestion
10. Shielding: 0.5 inch (0.7 cm) of Plexiglas (Low Z materials)
11. Special Considerations:

a. Safety glasses can provide eye protection.

b. Contamination is easily detected with G-M thin window probe.

c. Bremsstrahlung radiation may be a consideration for larger quantities.

d. Radioactive waste containers may need to be shielded with Plexiglas.

a. Safety glasses can provide eye protection.

f. ^{32}P tends to attach to ferrous materials and to glass, weak HCl (~0.1 N) can facilitate removal.

12. Typical dose rates from 100 µCi (3.7 MBq):

a. 3 mrad/hr at 1 cm

b. 0.03 mrad/hr at 10 cm

c. 0.002 mrad/hr at 40 cm

PHOSPHORUS-33 (^{33}P)

Phosphorus-33 is a low energy beta emitter. Most common means of detection is with a thin-window probe or liquid scintillation.

1. Maximum energy: 0.248 MeV (the average energy is 0.083 MeV)
2. Maximum range in air: 1.59 feet (0.5 m)
3. Maximum range in tissue: 1 mm
4. IAEA Radiotoxicity Classification: (Medium-low)

   Low hazard from 0.1 to 10 mCi

   Moderate hazard from 10 mCi to 1.0 Ci

   High hazard above 1.0 Ci
5. Physical half-life: 24.4 days
6. Effective half-life: 13.5 days
7. Critical Organ:

a. Bone - for transportable compounds

b. The lung and lower large intestine are critical organs for inhalation and ingestion

8. Personnel Monitoring: NOT detected with a dosimeter (TLD or film badge), dosimeter and finger rings, uptakes may be determined by urinalysis
9. ALI: 3 mCi (1 x 10^8 Bq) by inhalation, clearance in weeks

   6 mCi (2 x 10^8 Bq) by ingestion
10. Shielding: 0.25 inch (0.3 cm) of Plexiglas
11. Special Considerations:

Detection of P-33 by radiation survey instruments requires special care due to the low efficiency of detection.

SULFUR-35 (^{35}S)

Sulfur-35 is a low energy beta emitter similar to Carbon-14. Most common means of detection is with a thin-window probe or liquid scintillation.

1. Maximum energy: 0.167 MeV (the average energy is 0.056 MeV)

2. Maximum range in air: 10 inches (24 cm)

3. Maximum range in tissue: 0.32 mm

4 IAEA Radiotoxicity Classification: Medium-low

   Low hazard from 0.1 to 10 mCi

   Moderate hazard from 10 mCi to 1.0 Ci

   High hazard above 1.0 Ci

5. Physical half-life: 87.4 days

6. Effective half-life: 77 days

7. Critical Organ: Whole body and testis

8. Personnel Monitoring: Bioassay - urinalysis, NOT detected with a dosimeter (TLD or film badge)

9. ALI:

a. 10 mCi (4×10^8 Bq) inorganic compounds

b. 5 mCi (2×10^8 Bq) elemental sulfur

10. Shielding: 3 mm of Plexiglas but 1 cm required for rigidity

11. Special considerations:

Detection of S-35 by radiation survey instruments requires special care due to the low efficiency of detection.

^{35}S compounds frequently are volatile or produce volatile products; open and handle in a fume hood.

CHLORINE-36 (^{36}Cl)

Chlorine-36 is a medium energy beta emitter. Use a thin-end window G-M detector or liquid scintillation counter for detection.

1. Maximum energy: 0.71 MeV (the average energy is 0.233 MeV)
2. Maximum range in air: 7 feet (2 m)
3. Maximum range in tissue: 2.6 mm
4. IAEA Radiotoxicity Classification: High-medium
5. Physical half-life: 300,000 years
6. Effective half-life: 29 days
7. Critical Organ:

a. Whole body for transportable compounds

b. Lung for inhalation

c. Lower large intestine for ingestion

8. Personnel Monitoring: Urinalysis, finger rings
9. ALI: 0.2 mCi (7 x 10^6 Bq) by inhalation, clearance in weeks

   2 mCi (1 x 10^7 Bq) by ingestion
10. Shielding: 0.25 inch (0.6 cm) of Plexiglas
11. Special Considerations:

a. Cl-36 beta particles have sufficient energy to penetrate gloves and skin.

b. Contamination is easily detected with G-M thin window probe.

c. When handling millicurie quantities, do not work over an open container

d. Avoid glove and skin contamination or ensure that it is promptly detected and removed.

e. A high local dose can be received if the radioactive material is touched and allowed to remain in contact with the skin.

f. Safety glasses can provide eye protection.

CALCIUM-45 (^{45}Ca)

Calcium-45 is a low energy beta emitter and may be detected with a thin-window probe.

Calcium-45 is commonly used with animal studies.

1. Maximum energy: 0.257 MeV
2. Maximum range in air: 20 inches (52 cm)
3. Maximum range in tissue: 0.62 mm
4. IAEA Radiotoxicity Classification: High
5. Physical half-life: 163 days
6. Effective half-life: 163 days
7. Critical Organ: Bone
8. Personnel Monitoring: Bioassay - initially by urine, later by feces
9. ALI: 8 mCi (3 x 10^7 Bq) by inhalation

   2 mCi (7 x 10^7 Bq) by ingestion
10. Shielding: 3 mm of Plexiglas but 1 cm required for rigidity
11. Special Considerations:

Detection of Ca-45 by radiation survey instruments requires special care due to the low efficiency of detection.

CHROMIUM-51 (^{51}Cr)

Chromium-51 is a gamma and a x ray emitter. Most common means of detection is by scintillation.

1. Maximum energy: 0.32 MeV (9.8 %) very low energy (0.005 MeV) x-ray (22 %) and 0.004 MeV (66.9 %) auger electron
2. Maximum range in air: Data not available
3. Maximum range in tissue: Data not available
4. IAEA Radiotoxicity Classification: Medium -low
5. Physical half-life: 27.7 days
6. Effective half-life: 27 days;
7. Critical Organ: Lower large intestine and lungs
8. Personnel Monitoring: Dosimeter, internal uptakes may be determined by urine or fecal sampling
9. ALI: 20 mCi (7 x 10^8 Bq) by inhalation, yearly clearance

   20 mCi (7 x 10^8 Bq) by ingestion
10. Shielding: 3.2 mm of lead is the first half value layer (thickness of lead that will reduce the dose rate by one half
11. Special Considerations:

Use thin-end window G-M or solid scintillation detectors or liquid scintillation counting.

The exposure rate at 1 cm from 1 mCi is 180 mR/hr.

IRON-55 (^{55}Fe)

Iron-55 is a x ray emitter. Most common means of detection is by a G-M probe looking at the Mn x-rays that are emitted. Manganese is formed when the iron nucleus captures an electron. The manganese emits an x ray. Liquid scintillation counting may also be used.

1. Maximum energy: electron capture with an average low energy of 0.0006 MeV
2. Maximum range in air: Data not available
3. Maximum range in tissue: Data not available
4. IAEA Radiotoxicity Classification: Medium-low
5. Physical half-life: 2.6 years
6. Effective half-life: 370 days
7. Critical Organ:

   Liver and spleen for inhalation

   Lower large intestine for ingestion
8. Personnel Monitoring: Bioassay - uptakes evaluated by analysis of blood
9. ALI: 2 mCi (7 x 10^7 Bq) by inhalation, daily clearance

   9 mCi (3 x 10^7 Bq) by ingestion
10. Shielding: None (the penetration is extremely low).

COBALT-57 (^{57}Co)

Cobalt-57 is a gamma emitter. Most common means of detection is with a thin window G-M probe.

1. Maximum energy: Gamma radiation from, 0.014 to 0.692 MeV (0.122 MeV emitted 85.5 % of the time)
2. Maximum range in air: Data not available
3. Maximum range in tissue: Data not available
4. IAEA Radiotoxicity Classification: Medium-low
5. Physical half-life: 270.9 days
6. Effective half-life: 9 days
7. Critical Organ: Lower large intestine
8. Personnel Monitoring: Dosimeter, uptakes may be evaluated by whole body counting
9. ALI: 7 mCi (3 x 10^7 Bq) by inhalation, yearly clearance

   4 mCi (2 x 10^8 Bq) by ingestion;
10. Shielding: 3.2 mm of lead is the first half value layer.

IRON-59 (^{59}Fe)

Iron-59 is a beta and gamma emitter, which can create an external, internal, and skin and eye hazard. Iron-59 is detected with a thin-window end G-M probe, solid scintillator, or liquid scintillation counter.

1. Maximum beta energy:

   0.466 MeV (average energy is 0.155 MeV)

   0.273 MeV (average energy is 0.091 MeV)

   0.131 MeV (average energy is 0.044 MeV)

   Gamma energies:

   1.292 MeV; 1.099 MeV; 0.192 MeV; 0.143 MeV

2. Maximum range in air: 45 inches (115 cm
3. Unshielded dose rate from 1 mCi point source at 0.5 inch (1 cm): 6.18 rad/hr
4. IAEA Radiotoxicity Classification: Medium-high
5. Physical half-life: 44.6 days
6. Effective half-life: 42 days
7. Critical Organ:

Liver and spleen for inhalation; lower large intestine for ingestion

8. Personnel Monitoring: Dosimeter, finger rings - Fecal analysis may be used to determine uptake for weeks or months after handling. Urinalysis is recommended form 4-24 hours after handling;
9. ALI: 0.3 mCi (1×10^7 Bq) by inhalation

   0.8 mCi (3×10^7 Bq) by ingestion

10. Shielding: 9.7 mm of lead is the first half value layer
11. Special considerations:

a. Near an unshielded Fe-59 source, dose rates from beta radiation can be much higher than dose rates due to gamma radiation.

b. Avoid direct eye exposure.

c. Avoid skin exposure.

IODINE-125 (^{125}I)

Iodine-125 is a gamma and x ray emitter. Most common means of detection is by scintillation.

1. Maximum energy: 0.035 MeV gamma (6.5 %)

   0.027 MeV x ray (112.5 %)

   0.031 MeV x ray (25.4 %);
2. Maximum range in air: Data not available;
3. Maximum range in tissue: Data not available
4. IAEA Radiotoxicity Classification: Medium-high
5. Physical half-life: 60.0 days
6. Effective half-life: 42 days (Thyroid)
7. Critical Organ: Thyroid gland
8. Personnel Monitoring: Dosimeter, internal uptakes evaluated by thyroid scan
9. ALI: 0.06 mCi (2 x 10^6 Bq) by inhalation, daily clearance

   0.04 mCi (1 x 10^6 Bq) by ingestion
10. Shielding: 0.25 mm of lead is the first half value layer
11. Special considerations:

Volatilization of iodine (NaI) is the most significant hazard.

a. Simply opening a vial of sodium iodide at high radioactive concentrations can cause minute droplets to become airborne.

b. Solutions containing iodide ions should not be made acidic nor stored frozen.

c. Wear two pairs of gloves or polyethylene gloves over rubber. Some iodide compounds can penetrate surgical rubber gloves.

IODINE-131 (^{131}I)

Iodine-131 is a gamma, x ray and beta emitter. Most common means of detection is by scintillation.

1. Maximum energy: 0.248 - 0.606 MeV

   Primary gamma energies: 0.364 MeV

   0.637 MeV

   0.284 MeV

2. Maximum range in air: Data not available
3. Maximum range in tissue: Data not available
4. IAEA Radiotoxicity Classification: Medium-high
5. Physical half-life: 8 days;
6. Effective half-life: 7.6 days
7. Critical Organ: Thyroid gland
8. Personnel Monitoring: Dosimeter, internal uptakes evaluated by thyroid scan
9. ALI: 0.05 mCi (2 x 10^6 Bq) by inhalation, daily clearance

   0.03 mCi (1 x 10^6 Bq) by ingestion

10. Shielding: 2.3 mm of lead is the first half value layer
11. Special considerations:

Volatilization of Iodine (NaI) is the most significant hazard.

a. Simply opening a vial of sodium iodide at high radioactive concentrations can cause minute droplets to become airborne.

b. Solutions containing iodide ions should not be made acidic nor stored frozen.

c. Wear two pairs of gloves or polyethylene gloves over rubber. Some iodide compounds can penetrate surgical rubber gloves.

Section 12. Preparation of Work Areas and Materials

LEARNING OBJECTIVES:

STATE the preparation work areas and equipment.
IDENTIFY methods used to control radioactive contamination.
IDENTIFY the proper use of protective clothing.
EXPLAIN the purpose and use of personnel contamination monitors.

INTRODUCTION

This section is designed to assist the worker in preparing the workstation such that spread of contamination will be minimized.

A. APPROPRIATE SELECTION OF WORK AREA

The workstation should not present an exposure potential to another individual within the laboratory or to the adjacent rooms and spaces (other laboratories, offices or occupied spaces). The workstation should not conflict with the other work within the laboratory (such as a strong gamma emitter near low background counting equipment or a strong gamma emitter adjacent to office space where exposures are observed in the office area). Only workers with the appropriate level of training should be authorized to enter areas controlled for radiological purposes. The area which are restricted should be clearly identified to all workers frequently the area.

B. PREPARATION OF WORK AREAS

1. Minimize area:

Confine operations involving radioactive materials to as small a space as practicable.

2. Preparation of work area may include: (See figure 12.1)

- Clearing area of extraneous items and material
- Covering area as appropriate
- Marking and labeling area and materials

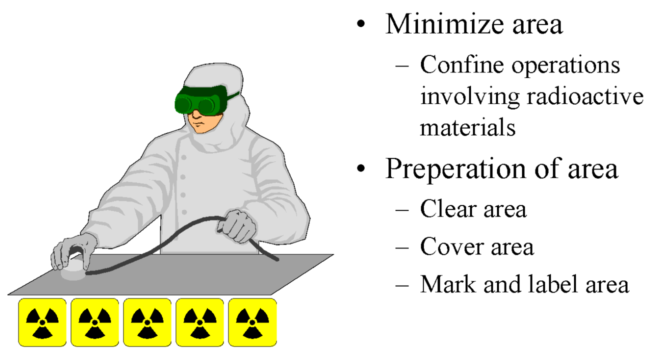


FIGURE 12.1 - WORKPLACE SETUP

3. Work surface:

Diaper paper (absorbent paper) should be placed absorbent side up. Use trays when appropriate.

4. Personnel contamination monitors

Personnel contamination monitors are used to detect radioactive materials on the skin and clothing. These are generally portable survey meters. This equipment should be calibrated and operational.

C. PREPARATION OF EQUIPMENT

1. Assemble survey meters:

The survey meter should be turned on and located in close proximity to the workstation. Position the detector such that it is directed toward the work area. This will enable workers to conveniently monitor hands during work and recognize when sources are open. Always work with the audio turned on. Personal safety and the safety of others must take priority over the concept that the sound may be disturbing to visitors or other workers.

2. Equipment preparation:

Use dedicated tools when appropriate. Cover or tape tools or equipment used during the job to minimize decontamination after the job when tools cannot be easily wiped down.

3. Assemble waste receptacles:

Receptacles for waste should be located by the workstation such that waste may be conveniently disposed of without contaminating the workstation.

4. Assemble materials and supplies:

Those supplies that would minimize small spills should also be within arm's reach while handling unsealed radioactive materials.

D. SHIELDING (IF APPROPRIATE)

Placement of shielding materials is critical to both personal safety and that of other colleagues. Work stations which require the use of shields should be located in corners or against walls so no worker on the opposite side of the will receive an exposure. However, if this cannot be accommodated, then shielding for the workstation on the opposite side of the workbench where another person may be working should be considered.

When shielding for both beta and gamma emitters, the shielding should be for the beta emitters first (closer to the radiation source). The beta shield should be closer to the radiation source to minimize the production of x rays from the beta emitter interacting with the lead (gamma) shield.

Beta Emitters

Optimum visibility and shielding needs are met with the use of Lucite "L" blocks. Remember all shields should be marked with the radiation symbol to prevent accidental exposure. Table 12.1 contains thickness of Lucite that will stop all of the beta particles for commonly used beta emitters.

Caution: Do not use thin layers of dense materials such as lead to shield beta emitters. Use of such materials may cause Bremsstrahlung (x ray) exposure.

Table 12.1

Beta Shielding for Common Radionuclides

Radioisotope	Minimum thickness (cm) of Lucite to stop all beta particles
H-3	None needed
C-14	<2 feet use 0.1 >2 feet - none needed
S-35	Same as C-14
Ca-45	0.1
P-32	0.8

Gamma Emitters:

Although lead glass gives the best visibility, lead sheets or bricks provide better attenuation. Lead "L" blocks with lead glass in a 45-degree angle top plate are a good compromise when visibility is the prime concern. Any lead glass or other shielding used (such as steel) should have a lead equivalency value specified below. In general, ten times the half value is adequate, as this will reduce the exposure by three orders of magnitude. By dividing the initial dose rate by one half, ten times, you will be left with less than 0.1 percent of the initial value. Table 12.2 contains half value layers of lead (Pb) for radionulcides commonly used in a general laboratory.

Table 12.2

Half Value Layers (Pb)

Radioisotope	Half Value Layer (Pb)
Na-22	1.00
Cr-51	0.20
Se-75	0.20
Rb-86	0.90

I-125	0.01
I-131	0.30

E. VENTILATION CONTROL

1. Airflow direction

Fume hoods are designed to maintain airflow from areas of least contamination to areas of most contamination (e.g., clean to contaminated to highly contaminated areas) such as fume hoods or glove boxes. The flow should be away from the body or operator.

2. Negative pressure

Slight negative pressure is maintained in buildings/rooms where potential contamination exists.

3. Filtration

High efficiency particulate filtration (HEPA) that removes radioactive particles from the air may be used. This is commonly required for high levels of radioactivity such as 10 percent of the Derived Air Concentration, DAC. Charcoal filters are required for specific nuclides that are in a gas form such as iodide.

4. Flow rate

Always check the flow rate or pressure in ventilated enclosures before starting operations. The flow rates of fume hoods must also go from least contaminated to most contaminated, see figure 12.2.

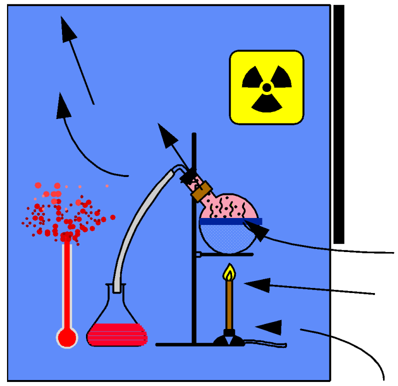


FIGURE 12.2 - FUME HOOD FLOW RATE

F. MARKING, LABELING, AND POSTING

1. Marking and Labeling

a. Mark and label area/materials as appropriate. Other workers should not have to guess what is contaminated or where the radioactive materials are located.

b. Do not discard intact radioactive labels/markings in normal trash!

Figure 12.3 is an illustration of the labeling.

- Mark and label area and materials as appropriate.
- Designation of areas

FIGURE 12.3 - LABELING

2. Designation of Areas

a. A radioactive materials area is an area or structure where radioactive material is used, handled, or stored.

b. A contamination area is any area where contamination levels exceed values listed in the appropriate regulation, but are less than or equal to 100 times those values.

The posting/signs will indicate:

CAUTION

CONTAMINATION AREA

3. High Contamination Area

Any area where contamination levels are greater than 100 times the values listed in the appropriate regulation is called a High Contamination Area.

4. Fixed Contamination

Fixed contamination designates levels greater than release values but not removable contamination.

5. Airborne Radioactivity Area

An airborne radiation area is where the measured concentration of airborne radioactivity, above natural background, exceeds either (1) 10 percent of the DAC averaged over 8 hours or (2) a peak concentration of 1 DAC. Derived Air Concentration (DAC), the breathing of an air concentration of one DAC for one working year (2000 hours) will result in a committed dose equivalent equal to an annual limit (i.e., 5 rem whole-body, 50 rem target organ).

6. Radiation Area

A radiation area is any area accessible to personnel where an individual could receive to a major portion of the whole body, a dose equivalent greater than 5 mrem in one hour at 30 cm (approximately one foot) from the radiation source or any surface through which the radiation penetrates.

G. PERSONNEL PROTECTIVE EQUIPMENT

Laboratory coats are intended to prevent contamination from spreading onto your personal clothing. If the coat is not buttoned-up, it will not prevent the spread of contamination. Approximately 1/3 of the contamination experienced by laboratory personnel is due to improper use of the personnel protective equipment.

Some compounds may be absorbed through the skin very easily. Wearing double gloves may be advisable. Change the outside pair of gloves often. Hands should always be surveyed when changing gloves.

1. Personnel Protective Clothing (Anti-Contamination or Anti-C)

a. Personnel protective clothing is used to protect your skin and personal clothing.

b. It does not provide protection from penetrating radiation such as gamma rays.

c. The degree of clothing required is dependent on the work area, radiological conditions and the nature of the job. Standard clothing requirements for low-level laboratory work are:

- Lab coat
- Surgeon's gloves
- Shoes without open toes
- Pants (provides increased protection of the legs compared to dresses)
- Safety glasses or equivalent for eye protection (i.e., from P-32)

2. Proper use of protective clothing

a. Inspect all protective clothing for rips, tears or holes prior to use.

b. Personal effects such as watches, rings or jewelry should not be worn in areas where contamination is expected.

c. After donning protective clothing such as anti-contamination clothing, proceed directly from the dress-out area to the work area. Most low-level laboratories do not require the use of anti-contamination clothing. In general, a lab coat is sufficient to protect the individual.

d. Avoid getting lab coats "wet." "Wet" lab coats provide a means for contamination to reach the skin/clothing.

e. Contact Radiation Safety Personnel if clothing becomes ripped or torn during operations and contamination is observed or suspected.

3. Eye protection

Safety glasses, goggles, or face shields may be used to protect the eyes from moderate to high-energy beta radiation, such as betas emitted from P-32.

4. Respiratory equipment

Respiratory equipment is used to prevent the inhalation of radioactive materials. Ventilation design should eliminate the need to use respiratory equipment except in extreme cases. This instructional course does not qualify a worker to wear respiratory equipment.


WEAR
PROTECTIVE
EQUIPMENT

Section 13. CONDUCT OF WORK - GOOD PRACTICE

LEARNING OBJECTIVES:

IDENTIFY the requirements for entry, working in and exiting Contamination Areas and Airborne Radioactivity Areas.
IDENTIFY the proper use of protective clothing.
IDENTIFY methods used to control radioactive contamination.
STATE the appropriate response to a spill of radioactive material.

INTRODUCTION

This section is designed to inform the worker of sources of radioactive contamination. It will also present methods used to control the spread of contamination. Contamination control is one of the most important aspects of radiological protection. Using proper contamination control practices will help ensure a safe working environment. It is important for all employees to recognize potential sources of contamination as well as to use appropriate contamination prevention methods.

A. PERSONAL PREPARATION

Before beginning a task, each worker must make sure he/she is ready to work has the following:

- Training to meet entry requirements.
- Knowledge of the standard operating procedures.
- Appropriate dosimetry.
- Personal Protective Equipment.

B. REQUIREMENTS OF POSTED CONTAMINATION AREAS

1. Requirements for entry

Meet the minimum requirements for entry into contamination areas, including:

- Radiation Worker training.
- Understanding of the specific procedures of the job/task.
- Personnel Protective clothing/equipment required for the job/task.
- Personnel dosimetry.
- Pre-job briefing for High Contamination Area and Airborne Radioactivity Areas.

2. Requirements for working in the area

- Avoid unnecessary contact with contaminated surfaces.
- When possible, wrap or sleeve materials and/or equipment brought into the area.
- Do not touch unexposed skin surfaces.
- No smoking, eating, chewing, drinking or applying cosmetic.

3. Requirements for exiting the area

a. Exit only at step-off pad (if provided). A step-off pad provides a "barrier" between contaminated and other areas to prevent or control the spread of contamination between areas. If more than one step-off pad is used, the final step-off pad is "clean" and is outside the exit point and is adjacent to the boundary of the contamination area.

b. Remove protective clothing carefully and slowly. Loose contamination on the clothing can be dislodged causing a possible spread of contamination or even inhalation if it becomes airborne.

c. Perform a personal survey. If contamination is indicated:

- Stay in the area
- Notify Radiation Safety Personnel
- Take action to minimize cross-contamination (e.g., put a glove on a contaminated hand or tape over contamination on clothing to prevent the spread of the contamination).

d. Tools or equipment being removed from a posted area must be monitored for release. This is typically performed with a portable survey meter.

e. After exiting and monitoring yourself, it is a good practice to wash hands.

C. DOSIMETRY

Always have proper personnel monitoring devices, which may include:

1. Whole body

The whole-body dosimeter, such as a thermoluminescent dosimeter (TLD), is worn outside of routine clothing (i.e., lab coat) between the collar and the waist. Whole body areas are identified as the major blood forming organs. See figure B.4.1.

2. Extremity monitoring

Finger rings if handling high contact dose rate materials such P-32. Ring badges should be worn on the hand that is expected to receive the greatest exposure. If exposures are experienced on a routine basis, the hand with the ring badge should always be the same. The badge should be underneath disposal gloves to prevent the dosimeter from becoming contaminated. Extremities are identified as the area from the elbows (most commonly the hands) and lower and the knees and lower, see figure 13.1.

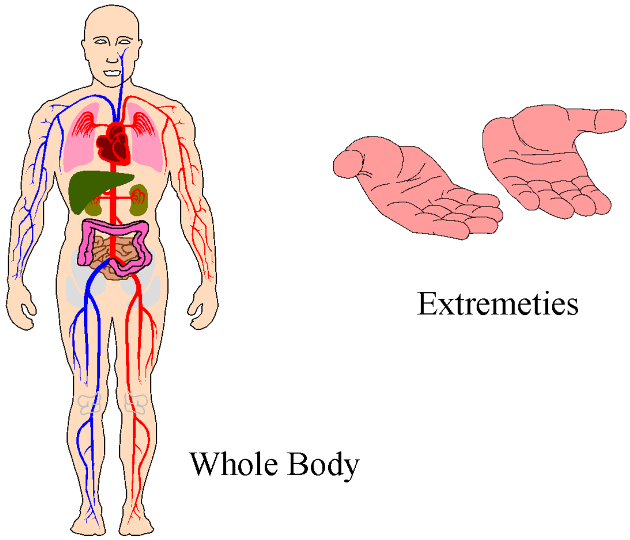


FIGURE 13.1 – WHOLE BODY AND EXTREMITIES

D. **PERSONNEL PROTECTIVE CLOTHING (ANTI-CONTAMINATION)**

The degree of clothing required is dependent on the work area, radiological conditions and the nature of the job. Most standard clothing in most low-level radioisotope laboratories is give below (see figure 13.2.):

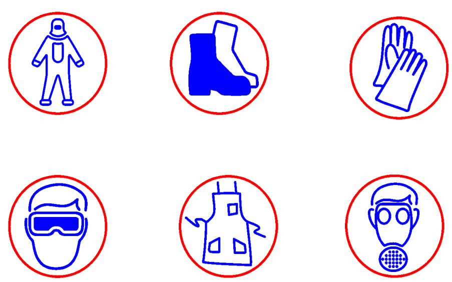


FIGURE 13.2 – PERSONNEL PROTECTIVE CLOTHING

Lab coat with long sleeves and buttoned or otherwise closed.

Surgeon's type of disposal gloves to protect hands.

Shoes without open toes.

Safety glasses are used to protect the eyes from high-energy beta emitters.

1. Proper use of protective clothing.

Inspect all protective clothing for rips, tears or holes prior to use. Personal effects such as watches, rings or jewelry should not be worn in laboratories where contamination is eminent. Protective clothing should not leave the laboratory if contamination is eminent or known. Avoid getting lab coats "wet." "Wet" lab coats provide a means for contamination to reach the skin/clothing. Contact Radiation Safety Personnel if clothing becomes ripped or torn during operations and contamination is likely.

2. Eye protection

Safety glasses, goggles, or face shields must be worn to prevent eye contamination in the event of splashes or droplet contamination. In addition, eye protection will provide protection from moderate to high-energy beta radiation such as betas emitted from P-32.

3. Respiratory equipment

Respiratory equipment is used to prevent the inhalation of radioactive materials. Ventilation design should eliminate the need to use respiratory equipment except in extreme cases. This training course does not qualify a worker to wear respiratory equipment.

E STORAGE AND CONTAINMENT OF RADIOACTIVE MATERIAL

Containment generally means using vessels, trays, absorbent paper or bench tops to contain contamination.

1. Storage areas

Store large bottles and containers close to the floor.

Shelves should be:

- Secured (bolted) to a wall
- Have lips or restraining cords to prevent bottles from falling
- Storage area should be well lit, properly ventilated, and have an even temperature

2. Radioactive materials should be properly stored

Store in an unbreakable container. If this is not possible, secondary containment (which is able to contain the entire volume of the primary container) should be used.

- In stable containers with secure means of closing.
- Away from sinks and drains or other possible pathways.
- Protected from adverse environmental factors.
- Away from combustibles and other fire sources.
- Protected from "unauthorized relocation", including locked refrigerators and storage cabinets.
- Clearly label outside of container with contents, especially if stored overnight.
- Provide instructions to open containers.

3. Posting of storage area

Room access and cabinets, refrigerators or freezers which house the container should be labeled “Caution: Radioactive Material” or “Caution: Radioactive Material Storage Area”. Do not store food in refrigerators located in radiation-controlled areas.

4. Chemical considerations for storage

Segregate incompatibles and store by hazard classification.

F. GOOD HOUSE KEEPING

“Good Housekeeping” is the **prime factor** in an effective contamination control program. It involves the interactions of all groups within the facility. Each individual must be dedicated to keeping his/her “house clean” to help control the spread of contamination.

G. GOOD PRACTICES

- **<u>Believe</u>** labels and posted areas.
- Avoid contamination and airborne radioactive areas. These areas should be isolated from routine operations.
- Treat radiological areas as if everything were contaminated.
- Minimize the number of items carried or placed into potentially contaminated areas.
- Use proper and functional radiation detection instrumentation.
- Do not eat, drink, apply makeup or chew gum.
- Always wash hands upon completion of work.

H. SPECIAL PRECAUTIONS FOR LIQUIDS

Radioactive solutions are a potential source of radioactive contamination if they are spilled or allowed to evaporate. A particular concern of a spill is that it may be a source of airborne radioactivity. In addition, when radioactive material is in a solution it can be carried to places not normally accessible, like under equipment.

1. Handling liquids

Standard good practices for handling liquids include:

- Using appropriate gloves for liquids being handled
- Protecting personal clothing

- Working in a tray with absorbent paper
- Using mechanical pipettes and dilutors. NEVER pipette by mouth!
- Working in a properly vented area
- Reporting any spills or suspected spills

2. Prevent spills

The best way to handle a spill is to prevent it in the first place by:

- Storing materials unless in use
- Limiting quantities to what is needed
- Keeping work area clean and free of obstructions
- Using stable containers with secure means of closing
- Avoiding unstable (top heavy) containers or arrangements
- Using secondary containment for liquids

3. Leaking containers

- Report all suspected leaks immediately to Radiation Safety Personnel.
- If the material is highly toxic, evacuate everyone from the area.
- Leaking containers should be placed in a fume hood if it can be done safely.

4. Handling spills

One simple method utilized for response to spills is the acronym SWIMS which stands for:

- **S**top the spill
- **W**arn others
- **I**solate the area
- **M**inimize exposure
- **S**ecure the ventilation system. If the spill involves a volatile chemical or volatile or gaseous radionuclides, the ventilation may need to be left on.

Section 14. PERSONAL PROTECTIVE EQUIPMENT

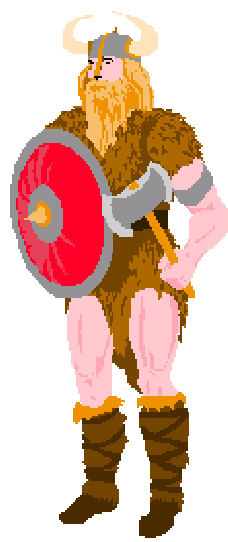
LEARNING OBJECTIVES:

DEFINE the limitations of Personal Protective Equipment.
DEFINE control points.
DISCUSS radiological control including contamination and dose rate.
DISCUSS the Donning and Doffing of protective clothing.
DISCUSS the selection factors of Personal Protective Equipment.
DISCUSS and demonstrate the methods for a personnel survey.
DISCUSS contamination control techniques.

INTRODUCTION

This section is designed to inform the worker of proper use of Personnel Protective Equipment. Personnel Protective Equipment is intended to prevent contamination from spreading onto personal clothing and skin. If it is not used properly, it will not provide the level of protection intended.

A. BASIC CONSIDERATIONS



Personal Protective Equipment – There are two basic considerations when choosing Personal Protective Equipment (PPE):

- It should provide protection from external radiation such as gamma radiation (i.e., lead apron, lead gloves or leaded glasses). The Radiation Safety Personnel should advise when this equipment is necessary.
- It should provide protection from radioactive contamination to minimize the potential for the contamination from getting onto skin or clothes and from entering the body. This is the most common PPE used in general laboratories. This equipment is NOT designed to provide protection from external radiation exposure. The criteria for the selection of PPE are for chemical considerations.

B. LIMITATIONS OF PERSONAL PROTECTIVE EQUIPMENT

Personal Protective Equipment has limitations. PPE is not designed for all hazards. The primary considerations in the design are for chemical and physical hazards/resistance.

1. Degradation

The obvious physical damage occurs at the areas where a chemical and/or physical substance agent has come into contact with the protective equipment and results in a chemical reaction with the material.

- A puncture through the equipment.
- Abrasion that passes through the clothing.
- A chemical reaction directly with the clothing.

2. Penetration

The leakage is due to design and construction faults. This may occur around seams or openings in the garment (i.e., zippers, buttons, etc.). This could also be caused by inappropriate equipment being used, such as the chemical or vapor reaching the wearer around the collar.

3. Permeation

The migration of a challenge chemical through a protective barrier is permeation. When liquid or vapor permeates through rubber or plastic material there is a three-step process:

- Sorption of the chemical at the outside of the PPE.
- Diffusion of the chemical through the PPE material
- Desorption of the chemical from the inside surface of the PPE to the wearer

4. Breakthrough time

Breakthrough time is defined as the amount of time it takes for the chemical to travel from the outside surface to the inside surface.

5. Factors which influence permeation

- <u>Temperature</u> - The rate of permeation increases in direction proportion to the temperature.
- <u>PPE thickness</u>:
  - Permeation is proportional to 1/thickness
  - Breakthrough time is proportional to the thickness
- <u>Solubility effect</u> - Solubility is the amount of chemical that can be absorbed by a given amount of PPE material.
  - Note: Low solubility does not necessarily mean low permeation rate.
  - Example: gases have low solubility but a high diffusion coefficient.

- Multi-component liquids - A mixture can be significantly more aggressive towards plastics and rubbers than single components.
- Persistent permeation - After a chemical has begun to diffuse into a plastic or rubber material, it will continue to diffuse after the chemical has been removed from outside surface.
- Chemicals will move from areas of high concentration to areas of low concentration.
- Concentration - The amount of material available to challenge the protective barrier is the concentration.

C. DESIGN AND CONSTRUCTION FACTORS TO BE CONSIDERED:

1. Durability (thickness, strength, lifetime)

Does the material have sufficient strength to withstand the physical stress of the task(s) at hand?

Will the material resist tear, punctures, and abrasions?

Will the material withstand repeated use after contamination/decontamination?

Can the required task be accomplished before contamination breakthrough occurs, or degradation of the PPE becomes significant?

2. Penetration related

How likely is it that chemicals will move through zippers, stitched seams or imperfections such as pinholes in the protective clothing?

3. Flexibility

Will the material and design allow sufficient flexibility of motion to perform the task?

4. Thermal limits

Will the material maintain its protective integrity and flexibility under hot and cold extremes?

5. Lot to Lot variations

Is the garment quality consistently good?

Is there great variability with certain manufacturers, models or clothing types?

D. SELECTION DECISION FACTORS

1. Work Function/Application

Compatibility with other equipment - Does the clothing preclude the use of another necessary piece of protective equipment?

2. Chemicals Involved

The individual components of clothing and equipment must be assembled into a full protective ensemble that protects both the worker from the hazards and minimizes the hazards and drawbacks of the PPE ensemble itself.

3. Degree of Exposure Contact

EPA has established four “Levels” (A, B, C, & D) of protective clothing to be worn by personnel when involved in the response to and/or mitigation of a hazardous waste emergency. The criteria established for the wearing of the various levels of protective clothing are:

Level “A” - Represents the highest available level of respiratory, skin and eye protection.

Level “B” -Provides the same level of respiratory protection but less skin protection than “A”.

Level “C” - Provides the same skin protection as “B”, but less respiratory protection.

Level “D” - Provides minimal skin protection, but not respiratory protection.

4. Reuse/Decontamination

Ease of decontamination:

Are decontamination procedures available on site?

Will the material pose any decontamination problems?

Should disposable clothing be used?

5. Cost Availability

Comparisons of cost and availability should be performed.

6. Responsibilities

- Identify the proper type of PPE to be used for a specific hazardous situation.
- Ensure that all affected employees have their own PPE.
- Monitor the integrity of PPE employees are using.
- Ensure that damaged or contaminated PPE is not used.
- Ensure that the PPE is used properly. A laboratory coat not buttoned up will not provide the intended level of protection.

E. GENERAL LABORATORY PERSONAL PROTECTIVE EQUIPMENT

- Personnel Protective Clothing (lab coat, gloves, shoe covers)
- Proper use of the protective clothing (use as designed)
- Eye protection (high energy beta emitters, chemicals)
- Respiratory protection
- Standard operating procedure

- Training

F. LABORATORIES WITH HIGHER LEVELS OF POTENTIAL CONTAMINATION

- Radiological areas that require protective clothing.
- Control points (location where access to and from contamination areas is controlled to minimize the spread of the contamination outside the area)
- Donning of protective clothing (putting on the protective clothing)
  - Inspect clothing for holes, rips or tears
  - Taping - on edges of pants, sleeves, front closure, and hood
  - No bunches or gaps permitted
  - Removal tabs on the taping
  - Start feet first and work up
  - Pants and sleeves go outside boots and gloves
  - Face piece must be under the hood
- Doffing of protective clothing (taking off the protective clothing)
  - Tape removal working from the top to the bottom
  - SCBA harness removal keeping face piece on (if applicable)
  - Jacket removal (inside out)
  - Face piece
  - Gloves (inside out)
  - Bib/overall removal (inside out to ankles)
  - Boot removal (step out to clean area)
  - Do not touch any of the outside surfaces of the protective clothing with hand, feet or body. It may be contaminated.
- Personnel surveys
  - Survey from the top to the bottom
  - Survey around the eyes, nose and mouth

15. Removing contaminated items from Junkyard III.

Decontaminating vehicle. About 50 contaminated vehicles found

16. Cutting up contaminated items for removal from the warehouse of Junkyard III.

improvised of filling eight drums simultaneously with contaminated soil.

Section 15. MONITORING FOR CONTAMINATION

LEARNING OBJECTIVES:

DEFINE the types of contamination to be monitored.
STATE when surveys should be performed.
IDENTIFY the typical methods of beta/gamma monitoring with portable survey meters.
STATE the information that must be documented during contamination monitoring.
DESCRIBE a whole-body survey.
DEFINE the information required to document a survey.

INTRODUCTION

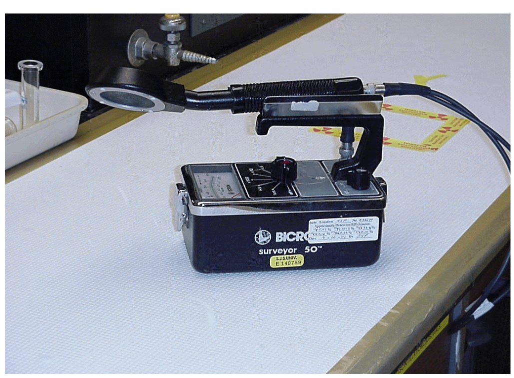
This section is designed to inform the worker of basic monitoring techniques for radioactive contamination. It will also present methods used to control the spread of contamination.

Contamination monitoring is one of the most important aspects of controlling contamination. Using proper monitoring methods will help ensure a safe working environment. It is important for all employees to identify sources of contamination as well as to use appropriate contamination prevention methods to minimize exposures to personnel and the environment.

A. CONTAMINATION MONITORING EQUIPMENT

Contamination monitoring equipment is used to detect radioactive contamination on personnel and work areas. There are two basic types of monitoring equipment, portable survey meters and counting equipment. Portable survey meters are generally used to identify the location of contamination and to differentiate between fixed and removable contamination. Generally, portable survey meters are qualitative. Counting equipment is used to quantify contamination and is generally referred to as quantitative.

For fixed contamination, always use radiation survey meters to identify the contamination. Tritium is the exception, as it cannot by readily detected with a portable survey meter.



For removable contamination, use both portable survey meters and wipe testing to identify contamination. Counting equipment, such as gamma counters and liquid scintillation counters is used to quantify the contamination levels, if they are removable. For tritium, portable survey meters (in general) are not used to identify contamination due to the low energy of the beta. A wipe test is required and is counted in a liquid scintillation counter.

While handling unsealed radioactive materials, monitor hands frequently during work. Monitor your hands and feet when leaving the workstation. Do personnel monitoring before leaving the laboratory. It is common to find contamination on the lab coat in the vicinity where it touched the workstation.

B. CONDUCTING SURVEYS - GENERAL

Regulatory agencies have provided general action levels for removable and fixed contamination above which specified control measures should be taken to protect against internal and external radiation exposure. For workers, the action levels are usually many orders of magnitude lower than those that, if the material were re-suspended, would produce maximum permissible concentration in air.

Good laboratory practice dictates that radiation surveys be made during and after experiments to ensure that sources are adequately shielded and that contamination is controlled. As a part of regulatory conditions (i.e. radioactive material license) facilities are required to survey their areas periodically and to document all surveys performed. The frequency of the surveys is dependent on the radioisotopes used, activity, physical properties, working conditions, and commitment to the regulatory agency. Typically, a schedule would be weekly or monthly. When the responsible user surveys weekly, the support group, such as Health Physics or Radiation Safety, would typically survey monthly.

Most radioisotopes used in research laboratories primarily involve the use of beta/gamma emitters. The following is typical for beta/gamma direct monitoring with portable survey meters:

- **Window**: Use a thin window probe. Detector window thickness (Mylar) should be not more than 2.0 mg/cm^2. Use a NaI detector when microcurie amounts are used of low energy gamma emitters.
- **Scanning**: Scan the surface. In most cases scanning will cover nearly 100% of accessible surfaces.
- **Distance**: Maintain detector window no more than 1/2 inch from surface.
- **Speed**: The number of counts produced in the detector is inversely proportional to the scanning speed. ANSI 13.12 (1987) describes a formula for calculating scan speed.
- **Audio**: If at any point, a perceivable audible or visual response is detected perform a stationary evaluation of count rate.

Most surveys require additional monitoring with counting equipment to measure removable contamination. These are referred to as smear or wipe surveys. Specifically, smear surveys differ from wipe surveys only by a known surface area. Wipe surveys are performed over a surface area of 100 cm^2. Smear surveys are performed over an undefined surface area. These tests should be expressed in counts per minute (cpm) or disintegrations per minute (dpm). Background samples shall always be prepared and counted along the area wipe tests. Areas found to be contaminated and in excess of two to three times background are to be decontaminated and resurveyed.

- An initial screening evaluation (not for final release) may be conducted by wiping 100% of surface.
- These large area wipes may be evaluated by holding the probe on to the wipe media (~ 5 seconds).
- Take representative disk smears (100 cm^2 area) of up to 100% of accessible surface areas.
- Wipe and smear surveys are counted in liquid scintillation counters, beta counters, or gamma counters. Sample preparation depends upon the counting system used.

C. AREA SURVEYS (See figure 15.1)

- Frequently monitor work areas.
- Monitor at the end of each shift.
- Monitor upon completion of work (or prior to taking a break and leaving the work).
- Monitor at least every 2 hours for work in progress.
- Wipe surveys should be performed on equipment and areas where survey instruments are not adequate to monitor contamination.

- Area Surveys
  - Frequently monitor work areas.
  - Monitor at the end of each shift.
  - Monitor upon completion of work or prior to taking a break and leaving the work.
  - Monitor at least every 2 hours.
  - Wipe surveys should be performed for contamination.

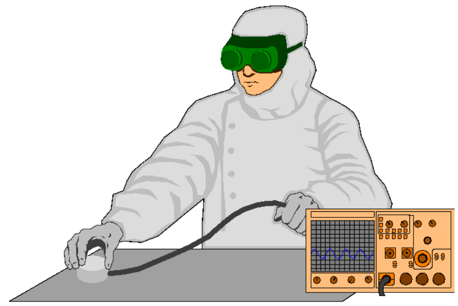
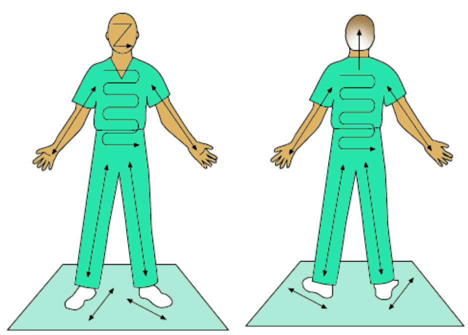


FIGURE 15.1 - AREA SURVEYS

D. PERSONNEL SURVEYS

A whole-body survey should take approximately 3 to 5 minutes. A full whole-body frisk is not generally necessary for routine bench top operations unless a spill occurs or contamination is found on the hands or face. The survey should be done before removing the laboratory coat and repeated if contamination is found.



The potential for personnel contamination, either external or internal, is normally identified through one of five monitoring methods:

- Count rate meter stations: external monitoring
- Personnel contamination monitors: external monitoring
- Partial monitors: external monitoring
- Whole body counts: internal (in vivo)
- Excreta analysis: internal (in vitro)

1. Work conditions:

In some cases, the presence of contamination is assumed prior to personnel monitoring:

- Exposure of individual to known contaminated liquid.
- Exposure of individual to airborne contamination without proper protective devices.
- Improper work practices within contamination area:

- Improper removal of protective clothing or devices
- Improper work practices with contaminated material
- Failure to follow the radiological control requirements
- Unknowingly working with material discovered to be contaminated

2. Proceed to survey in the following typical order:

- Head - Face/nose/mouth (pause at mouth and nose for approximately 5 seconds - concern for intake);
- Neck and shoulders
- Arms (pause at each elbow), hands and wrists; especially where gloves end

- Chest and abdomen
- Back, hips and seat of pants
- Legs and cuffs
- Shoe tops
- Shoe bottoms (pause at sole and heel)

If the count rate increases during frisking (such as the audible signal), pause for 5-10 seconds over the area to provide adequate time for instrument response.

If contamination is indicated (routinely identified as two times background):

- Remain in the immediate area
- Notify Radiation Safety Personnel
- Minimize cross contamination (such as putting a glove on a contaminated hand until decontamination can be attempted).

3. When monitoring, check hands before picking up meter.

- Hold the probe approximately 1/2 inches from surface
- Move probe slowly, 2 inches per second

E. DETECTION OF CONTAMINATION

Decontamination is the removal of radioactive materials from locations where it is not wanted. This does not result in the disappearance of radioactive material but involves the removal of the radioactive materials to another location. You must use the appropriate detection systems and methods to identify possible contamination.

F. COUNTING BETA EMITTERS

The most common radioisotope used in many general laboratories is beta emitters. An efficient counting method for beta emitters is by Liquid Scintillation Counting (LSC). The detector in this system is the scintillation fluid.

A general concept of how it functions is to view the fluid as having two molecules attached to each other. One is a solvent and the other is a fluor. As the radiation passes through the solvent it absorbs the energy and becomes excited. It needs to get rid of this energy. So it transfers it to the other molecule, the fluor. This molecule is much smaller than the solvent. It also wants to get rid of the energy. So it emits the energy as light in the yellow range. The photo multiplier tube observes the emitted light. The sample must be fully emerged in the fluid to be seen.

G. DECONTAMINATION OR NOT

If the presence of loose contamination is discovered, decontamination is a valuable means of control. There are special techniques used for decontamination that were derived from experience. In some situations, that is not always possible. There is an excellent list of decontamination techniques contained in National Council on Radiation Protection and Measurements (NCRP) Report Number 65; Management of Persons Accidentally Contaminated with Radionuclides, Bethesda, MD; 1980

1. Economic conditions:

Cost of time and labor to decontaminate location outweigh the hazards of any contamination present.

2. Radiological conditions

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

H. SURVEY DOCUMENTATION

A user survey log of each required survey (e.g. monthly) must be maintained in the appropriate file(s). A checklist is provided in the file that lists the compliance items Radiation Safety inspects during laboratory surveys. Review of these items for compliance with current practice within any laboratory is recommended. Figures 15.2 and 15.3 are the front and back of a typical survey form. The survey information generally includes the following:

- **A sketch of the laboratory**
- **Survey locations indicated on the laboratory sketch**
- **Survey instrument**
- Identification of the meter (or counting system) used (e.g. manufacturer, model, serial number). Note: survey meters must not be used if out of calibration.
- **Background measurement**
- Background radiation survey meter reading and/or counting of a "blank" sample during liquid scintillation counting.
- **Levels of contamination observed (including zeros)**
- **The date of the survey**
- **The name of the surveyor**

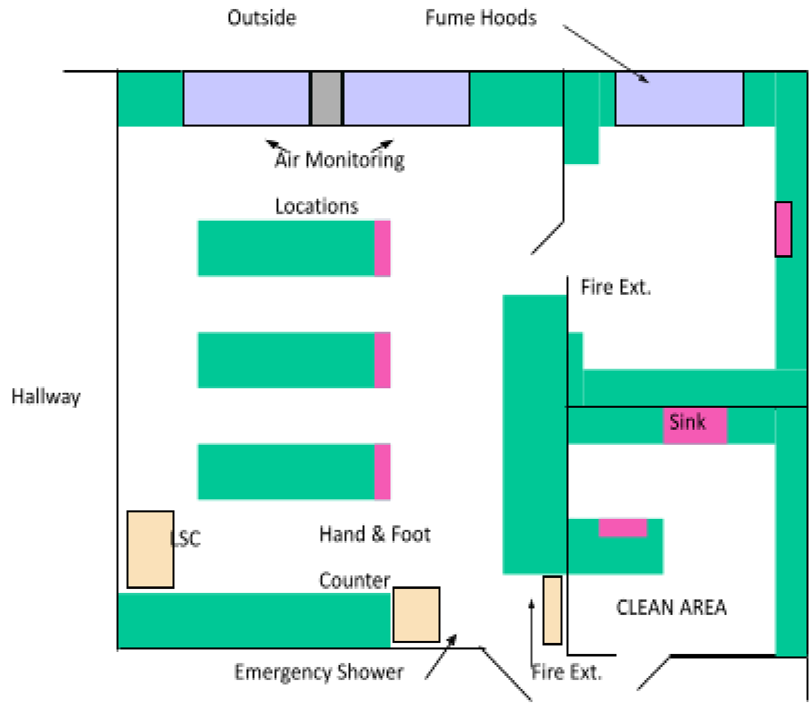


FIGURE 15.2 FRONT OF A FIELD SURVEY FORM

Field/Laboratory Contamination Survey Record

Survey Results and Data   Date: ________________________Page ___ of ___

Field surveys are performed when the location is reviewed for health and safety purposes. The illustration provides the survey locations. The illustration will display the instrument survey number or wipe sample number with the data provided below. The survey instrument will be a calibrated instrument that measures dose-rates in mr/hr or activity in cpm. The "S" number is the hand held survey instrument reading. The "W" number is the wipe sample data.

Survey location #	Background reading (mr/hr) or (cpm)	Instrument reading (mr/hr) or (cpm)	Remarks or corrective action	Initials
S-01				
S-02				
S-03				
S-04				
S-05				
S-06				
S-07				
S-08				
S-09				
S-10				

Instrumentation:

Wipe sample location #	Background reading (cpm)	Net counts (cpm)	Remarks or corrective action	Initials
W-01				
W-02				
W-03				
W-04				
W-05				

W-06				
W-07				
W-08				
W-09				
W-10				

Model ___________________ Serial Number ________________ Calibrated _________________

Counter:

Model ___________________ Serial Number ________________ Calibrated _________________

Reviewed by: ___________________________________

(Signature)

FIGURE 15.3 BACK OF A FIELD SURVEY FORM

Section 16. RELEASE OF MATERIALS

LEARNING OBJECTIVES:

DEFINE releases to controlled and unrestricted areas.
DEFINE what background levels should be present during surveys and why.
EXPLAIN the method for direct monitoring of beta/gamma sources.
DEFINE the areas to be monitored for wipe surveys per sample.
DEFINE the proper method to perform swipe surveys (area, pressure).
EXPLAIN the proper method for packaging and submittal of swipes.
EXPLAIN the proper method for preparation of tritium swipes.

INTRODUCTION

This section is designed to inform the worker of the various methods used to allow for the release of equipment and other sources that were previously contaminated. It will also present methods used to control the spread of contamination.

Contamination control is one of the most important aspects of radiological protection. It is important for all employees to recognize when equipment and other sources of previously contamination can be released and when they cannot.

A. RELEASE TO UNCONTROLLED AREAS

Prior to being released, property must be surveyed to determine whether both removable and total surface contamination (including contamination present on and under any coating) is greater than the regulatory limits.

Property shall be considered potentially contaminated if it has been used or stored in radiation areas that could contain unconfined radioactive material or that are exposed to beams of particles capable of causing activation.

Material and equipment in radiological areas, established to control surface or airborne radioactive material should be treated as potentially contaminated, see Table 16.1.

B. UNRESTRICTED RELEASE

The release of property to uncontrolled areas must be in accordance with established regulations and guidelines, such that possession and utilization is granted without regard or concern for residual radioactivity content. Items identified for release should be surveyed for fixed/removable contamination to determine the highest level of contamination. Do not confuse this process with decommissioning of a facility. That process is much more restrictive and requires much more coordination with the regulatory agency.

C. MONITORING TECHNIQUES - GENERAL

Monitoring for release of materials is addressed in regulatory guidance. The following techniques apply for G-M detectors (^3H cannot be measured by this method). Particular attention should be paid to areas where radioactive dirt, fluids, or particles could impinge, settle, or accumulate. Also, areas where surfaces mate (e.g. flanges), equipment with moving parts (e.g. fans, or pump internals), and equipment used to transport or store radioactive liquids or gases should be thoroughly surveyed.

TABLE 16.1

Surface Radioactivity Guides

NUCLIDE (1)	**REMOVABLE (2,4)**	**Total (2,3) FIXED PLUS REMOVABLE**
U-natural, U-235, U-338 and associated decay products	1,000 dpm α/100 cm^2	5,000 dpm α/100 cm^2
Transuranics (including Pu), Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	20 dpm/100 cm^2	300 dpm/100 cm^2
Th-natural, Th-232, Sr-90, Ra-224 U-232, I-126, I-131, I-133	20 dpm/100 cm^2	1,000 dpm/100 cm^2
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except for Sr-90 and other noted above (5)	1,000 dpm β-γ/100 cm^2	5,000 dpm β-γ/100 cm^2

(1) Where surface contamination by both alpha and beta-gamma-emitting nuclides exists, the limits established for alpha and beta-gamma-emitting nuclides should apply independently.

(2) As used in this table, dpm (disintegrations per minutes) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background and efficiency and geometric factors associated with the instrumentation.

(3) The levels may be averaged over one square meter provided the maximum surface activity in any area of 100 cm^2 is less than three times the guide values.

(4) The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate

pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of surface area less than 100 cm^2 is determined, the activity per unit area should be based on the actual area, and the entire surface should be wiped.

(5) This category of radionuclides includes mixed fission products, including the Sr-90 that is present in them. If does not apply to Sr-90 which has been separated from the other fission products or mixtures where the Sr-90 has been enriched.

1. General Guidance

a. Surveys should be conducted in a low background area (background levels are not to exceed 100 cpm).

b. Direct measurement shall be made prior to smear or wipe surveys.

c. Materials or equipment with inaccessible surface areas should be disassembled for survey or the inaccessible areas evaluated for contamination with special survey techniques or by review of process knowledge.

d. An audible response shall be utilized as the principal indicator for initial detection of surface radioactivity.

e. The assigned instrument/detector efficiencies shall reflect a prior evaluation of facility wastes.

Typical efficiencies for a thin window probe.

- ^{14}C 10%
- ^{35}S 10%
- ^{32}P 50%

2. Swipes for Release or Transportation (does not apply to tritium)

a. Prior to taking a wipe for release purposes, the item should be swiped according to the instructions below.

b. If contamination is detected, the item should be decontaminated and resurveyed prior to taking official wipes.

c. Items wiped for release should be surveyed for fixed/removable contamination to determine the highest level of contamination.

d. Transportation packages may exhibit radiation levels due to the contents. Therefore, direct surveys for highest radiation levels have little correlation with removable contamination. If removable contamination is detected, the item should be decontaminated and resurveyed prior to taking official wipes. Under certain conditions, packages can be offered for transportation with residual contamination (49 CFR 173.443).

3. Swipes on Suspected Contaminated Surfaces (does not apply to tritium)

a. Perform a general survey for fixed/removable contamination to prevent swiping in areas of gross contamination.

b. For surfaces likely to be contaminated use a portable G-M meter with a thin window beta/gamma probe to screen for elevated levels of radioactive contamination and prevent cross contamination.

c. Removable contamination can be measured by taking area samples (swipes). Use tissue or other absorbent materials. Then counting directly with a portable G-M meter with a beta/gamma probe (pancake probe).

d. If contamination is detected, it may be prudent to decontaminate before taking a swipe. If the existing contamination level must be determined, be very careful not to spread contamination or produce any airborne radioactivity.

D. BETA/GAMMA DIRECT MONITORING

1. Window

Use a thin window probe. The detector window thickness (Mylar) should be not more than 2.0 mg/cm^2.

2. Scanning

Scan the surface. In most cases scanning will cover nearly 100% of accessible surfaces.

3. Distance

Maintain detector window no more than 1/2 inch from surface.

4. Speed

The number of counts produced in the detector is inversely proportional to the scanning speed.

5. Audio

If at any point, a perceivable audible or visual response is detected, perform a stationary evaluation of the count rate.

E. WIPE (SWIPE) SURVEYS AND TECHNIQUES

Wipes are taken to detect the presence of removable contamination on a material. Wipes can provide official documentation for release of items to uncontrolled areas and packages submitted for transportation. In general a wipe is an absorbent material smeared over a 100 cm^2 area and counted for removable radioactivity. A swipe is the same activity; however, the surface area is undefined and more limited.

1. Wipe Area

a. An initial screening evaluation (not for final release) may be conducted by wiping 100% of the surface.

b. These large area wipes may be evaluated by holding the probe up to the swipe (≈ 5 seconds).

c. Take representative disc smears (100 cm^2 area) of up to 100% of accessible surface areas.

2. Materials

Any soft absorbent material can be used, such as Kimwipes or cheese cloth.

3. Pressure Area

The wiping material should be folded over and the pressure area (the area that will be in contact with the surface) should approximate the area of the detector. This does not work for all situations depending on the size and configuration of the item.

4. Inaccessible areas

If portions of the item are inaccessible and there is potential for internal contamination, efforts must be made to survey the internal surfaces either by disassembly or some other method such as sampling internal fluids or flushing internal surfaces and counting the effluent. If this is not possible or feasible, the item cannot be released for unrestricted use. If there are any questions, contact Radiation Safety personnel.

F. DOCUMENTATION

<u>All surveys for unrestricted release shall be documented in writing</u>. When regulators review your records, they go by the concept that if is not in writing than it has not been done.

1. Official Wipes for Release Surveys

Areas of 100 cm^2 should be selected either on individual surfaces or a combination of surfaces. A surface area of 100 cm^2 is equivalent to the surface area of a dollar bill. As a general rule, one to five wipes should be taken for every square meter of representative surface area to be surveyed.

2. Surfaces Greater than or Equal to 100 Square Centimeters

If the total surface area of the item to be wiped is greater than 100 cm^2 representative areas should be wiped on all surfaces.

3. Representative Area

Setting specific criteria as to what constitutes a representative area in each case is extremely difficult. The item, material or equipment and its history must be known sufficiently to determine the number of wipes required to adequately document that all portions of the item, material or equipment are not contaminated. If that information is not available or unknown, more wipes should be taken. A thorough survey with a thin window detector or area wipe could be used to provide a general idea of contamination levels before using swipe tabs.

4. Official Wipes for Packages Submitted for Transportation

To determine the removable contamination levels on packages submitted for transportation, an area of 300 cm^2 per wipe should be taken.

Section 17. DECONTAMINATION

LEARNING OBJECTIVES:

IDENTIFY when decontamination may not be recommended.
IDENTIFY methods for preventing contamination.
DEFINE the control factors for actions to be considered during skin contamination.
DEFINE the method of skin decontamination.
DEFINE material decontamination.
IDENTIFY the normal methods used for decontamination.

INTRODUCTION

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

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

A. DECONTAMINATION OR NOT

If the presence of loose contamination is discovered, decontamination is a valuable means of control. Decontamination is the removal of radioactive materials from locations where it is not wanted. This does not result in the disappearance of radioactive material but involves the removal of the radioactive materials to another location. In some situations, this is not always possible.

1. Economic conditions

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

2. Radiological conditions

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

B. PREVENTIVE METHODS

- Identifying and repairing leaks before they become a serious problem.
- Changing out gloves or protective gear as necessary to prevent cross-contamination of equipment.
- Good housekeeping is the best method of prevention. If the material and equipment is not available to become contaminated, there will be less to decontaminate in the event of a spill.

C. SKIN DECONTAMINATION

Once it is determined that the worker is contaminated, the actions taken will be controlled by three basic radiological control factors:

- Physical condition of the worker.
- Location of the contamination on the worker.
- Activity of the nuclide(s) present.

Primary consideration should be given to the physical condition of the worker. All action taken by the Radiation Safety personnel will be based on the workers physical condition. The major concern should be whether or not the worker has a serious injury. When a worker sustains a serious injury, the primary concern is the first aid or assistance the worker needs. When a worker sustains an injury, the extent of the injury needs to be determined. Conditions that should be investigated include open/puncture wounds, bruises, sprains, strains and fractures.

Once the physical condition of the worker has been identified, the location of the contamination needs to be determined. Some of the items to pay particular attention to include:

- Is contamination localized on skin surface?
- Is contamination located on or near a body orifice?
- Is contamination located near a break in the skin?
- Is there a skin condition present in the vicinity of the contamination?

Include a determination of the type of activity (alphas, beta or gamma) and save some type of sample for laboratory analysis.

Skin contamination normally does not cause physical injury to the skin. Some nuclides and chemical forms allow absorption through the skin (i.e., iodide and tritium). Strong beta emitters may present a hazard to the skin.

Intact skin is an excellent barrier, so use gentle methods to decontaminate. Normally, mild soap and lukewarm water is used to decontaminate personnel. There are several guidelines to follow:

- Do not abrade skin
- Do not chap skin by cold water or harsh chemicals
- Do not spread the contamination
- Avoid hot water because it will open pores
- Use mild soap, not detergents or abrasives

1. Notify the Radiation Safety personnel for assistance in monitoring and decontamination.

Stay put so as not to spread contamination.

2. Cover area if possible, to prevent airborne and cross contamination.

Put on a glove.

Put on booties to keep from tracking contamination.

Tape loose contamination on lab coat or coveralls.

3. Carefully remove clothing by rolling inside out, and place in contaminated laundry.

This will keep the contamination rolled in the clothing.

4. Often some skin contamination remains.

A common procedure is to wear surgeon's gloves overnight to induce sweat that will lift contamination from the skin.

D. MATERIAL DECONTAMINATION

Material decontamination is the removal of radioactive materials from tools, equipment, floors and other surfaces in the work area, see figure 17.1.

- Establish control to prevent the spread of contamination.
- A high priority is the prevention of airborne contamination.
- Decontaminate from area of low to high contamination. An exception is when potential for airborne contamination is high.
- Decontaminate from top to bottom so that contamination will not run down on the clean surface.
- Only make one pass, then discard or turn wipe to a clean surface. Do not re-contaminate an area.

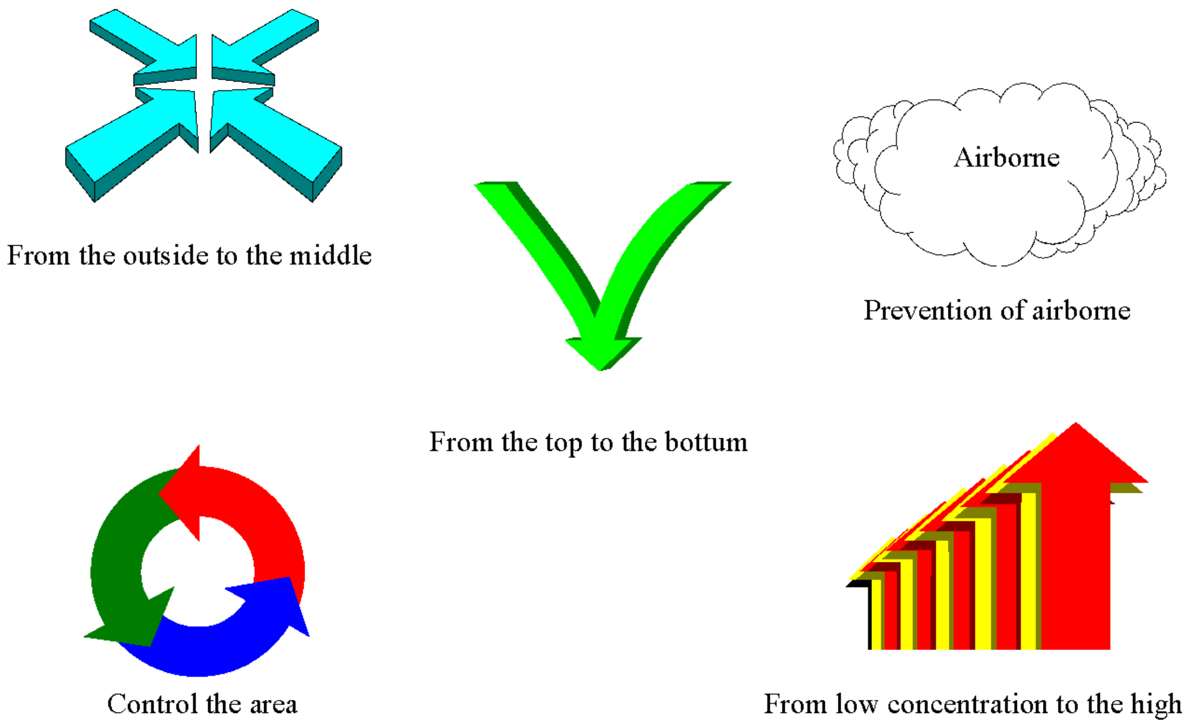


FIGURE 17.1 - DECONTAMINATION TECHNIQUES

Section 18. PORTABLE SURVEY METERS AND COUNTING SYSTEMS

LEARNING OBJECTIVES:

IDENTIFY the correct instrument (from a list of common types of radiation survey instruments) for the detection and measurement of the basic types of ionizing radiation.
IDENTIFY the response characteristics and limitation of the radiation survey instruments commonly used.
IDENTIFY the proper operational checks for portable survey meters.
EXPLAIN the methods of calibration, source checks and background measurements.
EXPLAIN the basic techniques for surveying areas and personnel.

INTRODUCTION

This section is designed to inform the worker of use of survey instruments commonly found in basic research laboratories. It will also present methods used to perform basic surveys of areas and personnel, primarily when radioactive contamination is a concern.

Contamination control is one of the most important aspects of radiological protection. Using the survey instrument properly is paramount to contamination control practices and will help ensure a safe working environment.

A. BASIC SELECTION

1. Exposure

To measure exposures, instruments should be calibrated in R/hr or mR/hr. In general, this is looking at the energy deposited by unit mass.

2. Contamination

To measure material, instruments should be calibrated in counts per minute (cpm). This contamination can be removable, fixed, or a combination of the two. Removable contamination represents a greater hazard. Methods of detection should be used which can detect fixed or removable contamination, and differentiate between the two. The two most common portable survey meters are those with a Geiger-Mueller (G-M) detector and with a scintillation detector.

The Table 18.1 below provides basic guidance in the selection of appropriate instruments to measure or detect radioactive contamination. Identify those radionuclides that are handled. Select the appropriate instrument(s) based on both the need for portability and the sensitivity of the instrument for the characteristic radiation emitted by the radionuclide in question.

TABLE 18.1

Selection of Appropriate Instruments

Characteristic Radiation	**Portable Instruments**	**Non-Portable Instruments**
Low energy beta ^{3}H, ^{63}Ni		<u>H</u>, <u>E</u>, F
Medium energy beta ^{14}C, ^{35}S, ^{45}Ca	<u>A</u>, (C, D) for associated Bremsstrahlung	<u>G</u>, <u>H</u>, E, F
High energy beta ^{32}P	<u>A</u>, B, (<u>C</u>, D) for associated Bremsstrahlung	<u>G</u>, <u>H</u>, E, F
Low energy gamma (or x ray) ^{125}I	<u>C</u>, D	<u>I</u>, <u>H</u>, (E, F, G)
Medium-high energy gamma ^{131}I, ^{22}Na	<u>D</u>, A, B, C	<u>I</u>, G, E, F, H, I

A = Ratemeter with end window or pancake G-M probe.

B = Ratemeter with thin wall G-M probe.

C = Ratemeter thin NaI(Tl) scintillation probe.

D = Ratemeter thick thin NaI(TL) scintillation probe.

E = Ratemeter with gas-flow proportional counter.

F = Open window gas-flow proportional counter.

G = Closed window gas-flow proportional counter.

H = Liquid scintillation counter (LSC).

I = Gamma spectrometer with semiconductor or scintillation detectors.

__ = Superior.

( ) = Limited usefulness.

3. Desirable features of G-M survey instruments

- Paralysis protection: sometimes an option at extra cost
- Audible output: sometimes an option at extra cost
- Coil cord, if detachable probe: sometimes an option
- Large diameter probe: extra cost for most instruments
- Response data for different radiation
- Available service and parts
- Reliability
- Commonly used batteries

B. OPERATIONAL CHECKS

The amount of radioactivity that has been detected by direct monitoring or by wipe survey can be readily estimated by subtracting the background count rate (background cpm) from the observed count rate (gross cpm) and then dividing the net count rate by the counting efficiency (c/d) for the radionuclide in question.

$$\frac{\text{(gross cpm) - (background cpm)}}{\text{efficiency}} = \text{net dpm}$$

Always express contamination levels in standard units, such as dpm or microcuries/100 cm^2. If the identity of the radionuclide detected is not known, the most conservative (lowest) efficiency of the possible radionuclides should be used. Table 18.2 provides efficiencies for portable survey meters for selected radionulcides.

TABLE 18.2

Conservative Survey Instrument Efficiencies

Radionuclide	Beta Energy MeV maximum	Beta Energy MeV average	Range in air	Efficiency %
Tritium	0.0186	0.0057	1/4 inch	0

Carbon-14	0.156	0.045	9 inches	10
Sulfur-35	0.167	0.0488	12 inches	10
Strontium-90	0.546			45
Phosphorous-32	1.71	0.69	20 feet	50 approximate

1. Pre-operational checks should always be performed

a. Check the **calibration** sticker to ensure that the instrument's calibration is valid. Because the calibration is not valid does not mean that the instrument is not operational. It does mean that it cannot officially be used for health and safety purposes. Regulations dictate how to calibrate and when to calibrate portable survey meters. Most calibration cycles are one year.

b. **Check the battery**.

With most programs this is the only feature that the operator may change without invalidating the calibration.

If the batteries have expired, replace them. An occasional check during the day's activities will identify if the instrument is still operational.

c. **Turn on the audio.**

The audio on the instrument has a faster response time than the dial reading. By using the audio as an indicator for possible contamination, the operator is left free to visually concentrate on the location of the probe rather than on the meter. This should help prevent placing the probe in the contamination and reducing the effectiveness of the instrument.

d. **Source check** - make sure that the instrument responds.

The source check should have a known response on the instrument. It is not recommended to use short-lived radionuclides as a source check. The response on the instrument should not vary over time. When the instrument is checked with the source at one time of the year, it should respond the same any other time of the year.

e. **Check the background**.

Know the background radiation levels. This should be twice when using the instrument, both at the beginning and end. In general, most laboratories try to identify low levels of contamination. For most operations, this is about two times the background.

2. Periodical checks

Operational checks and source checks will identify problems while the instrument is in use.

3. Post-operational checks

Source check and battery check should be performed at the completion of the work. This will identify if the instrument battery expired or if the instrument malfunctioned. If the instrument is no longer functional for either reason, there may be potential contamination spreading which the operator was not aware.

C. LIMITATIONS

To measure the activity, the radiation must somehow get into the detector. Radioactivity is emitted randomly in every direction. Charged particles, such as alpha and beta particles, have a finite range of travel in air.

1. Range dependent for charged particles.

The detector must be close to the source to be observed. Weak beta sources (^{3}H) will not penetrate the window of portable survey meters routinely used in general laboratories.

2. Instruments are normally calibrated with a gamma source (^{137}Cs).

Beta sources under respond with G-M detectors.

Alpha sources over respond with G-M detectors.

3. Instruments may be subjected to environmental sources (i.e. RF, Pulses, magnetic field interference, position to earth). A radar can affect the reading.

4. The probes of G-M detectors are very thin and can be easily punctured. The window is made to be equal to the dead layers of skin.

5. The meter dial and the audio do not respond at the same rate.

The audio is much faster at responding to observed activity. The meter dial requires a specific time for the electronics to respond.

6. Survey instrument are normally qualitative and not quantitative. They will tell if something is there but not how much.

7. Window may be too thick and provide a low response or no response at all. The radiation must get inside the probe to be detected.

8. Batteries may die or be low at inopportune times. Many surveys were performed with dead batteries. The results often left contamination undiscovered.

9. Calibration may drift. The electronics can drift. Check the instrument regularly with a known source with a long half-life. The readings should be consistent.

10. Short in cable or other electronic problems may occur. If the readings or sounds suddenly increase when the cable to the probe is moved, there is a short circuit in the system.

11. A high radiation field may peg the dial and respond as a low radiation field. Some instruments will read zero when the instrument is saturated.

12. Poor survey techniques may cause problems. The angle of the probe to the source may result in only partial detection of the activity. Radiation is absorbed by air if the probe is too far from the source.

D. CALIBRATION, SOURCE CHECKS AND BACKGROUND

Portable survey meters are calibrated by subjecting the instrument to a known gamma field. The electronics are adjusted (as much as possible) to the field to obtain a reading that can normally vary +/- 10 to 15 percent (depending on the manufacturers recommendations).

1. Instruments are routinely calibrated on a periodic schedule, most often annually. An experienced health physics technician should perform calibration of survey instruments.

2. Only calibrated instruments are authorized to be used for health and safety purposes. Instruments used for monitoring contamination are identified as being used for health and safety.

3. The operational status of the instrument should be verified by comparing it to a known source of radiation (source check). This source should be a long-lived source such that the response on the instrument should be the same over time.

4. A background check should be performed at the beginning and end of the work period or day. An increase in the background would suggest contamination is be spreading.

E. BASIC SURVEY TECHNIQUES (AREA AND PERSONNEL)

Surveys are to be conducted periodically according to the use of radioactive materials. The frequency is dependent upon the license commitment. Technique dependents upon:

1. Characteristics of the radionuclide

What is the most appropriate instrument for contamination surveys?

2. Chemical characteristics of the compound.

To what location will the compound be transported?

Does the chemical preclude observation and relocation?

Does the compound present any other risks (e.g. biohazard)?

3. Fixed, removable or airborne contamination

Wipe test versus survey instruments.

4. Physical properties

Is the contamination a liquid, dry powder or gas?

Where is the contamination?

5. The activity being surveyed

Are you surveying low background areas being surveyed?

Instruments may be a screening technique and counting equipment a primary discriminator for contamination.

Is surveying for high gross contamination being done?

The survey instrument may be the primary discriminator for contamination.

Is the sensitivity of the instrument sufficient for the task?

6. Other considerations:

a. Risk to the surveyor

b. Instruments available

c. Counting statistics

When surveying for contamination on people, always start by removing the clothing in the area where the contamination is located. If the contamination engulfs the entire individual, by removing the clothing most of the contamination is removed. The survey should then proceed at the head, concentrating around the mouth and nose to determine if radioactive material entered the body by inhalation. Then proceed to survey the front of the body from the top to the bottom followed by the survey of the back of the body from the top to the bottom. A whole-body survey should take 3 to 5 minutes.

F. Liquid Scintillation Counters

The Liquid Scintillation Counter (LSC) is one of the more common counting systems used in the general laboratory. It is most often for measuring low energy beta emitters on wipe and leak test samples. Tritium is the lowest know energy beta emitter. The LSC is the preferred method of measurement for tritium.

The LSC instrument has a very high counting efficiency because the activity being measured is immersed in the scintillation cocktail. Conceptually, the scintillation fluid is the mechanisms of detection. The fluid is made up of two components; the solvent and the scintillating solute. The purpose of the solvent is to dissolve both the radioactivity and the scintillating solution. The radioactivity may be in an organic chemical used in research activities such as a tracer, animal tissue or in urine samples or wipe test media. The solute absorbs the decay energy from the solvent and re-emits the energy as light.

Solvent-Solute systems:

- Solvents – aromatic hydrocarbons, toluene, xylene, etc. & ethers, anisole and p-dioxane

Must have good energy transfer characteristics

- Solutes – primary and secondary fluors
    - **Primary** – oligophenylenes, oxazoles, oxadiazoles, i.e., p-terphenyl, PPO (2,5-diphenyloxazole)
    - **Secondary** – POPOP [1,4-bis-2-(5-phenyloxazolyl)-benzene], Dimethyl-POPOP [1,4-bis-2-(4-methyl-5-phenyloxazolyl)-benzene]

The intensity of the light flash produced following absorption of radiation energy is directly proportional to the energy deposited in the scintillation fluid. Beta energies (and alpha energies) can be measured and some energy discrimination is possible. Beta emitters release a whole range of energies from zero to the maximum energy associated with the particular beta emitter.

With the beta (or alpha) sample internal in the scintillation fluid the efficiency is increased because the geometry is 100 percent due to the range of the emitter.

The counter contains two photomultipliers (PM) aimed at the transparent scintillation vial holding the fluid and sample. See Figure 18.1. This reduces the background count. Sometimes random counts are produced by noise pulses in the photocathodes of the two PM tubes. These counts are rejected by the "coincidence circuit" in the LSC. The circuit allows the pulse to pass through only if it receives a pulse simultaneously from both PM tubes. The light flashes in the scintillation meet this requirement of occurring coincidentally in time. The pulses that pass through go to the pulse height analyzer that sorts the pulses according to their amplitude (energy) and routes the different energy pulses to the correct scaler where a count is recorded.

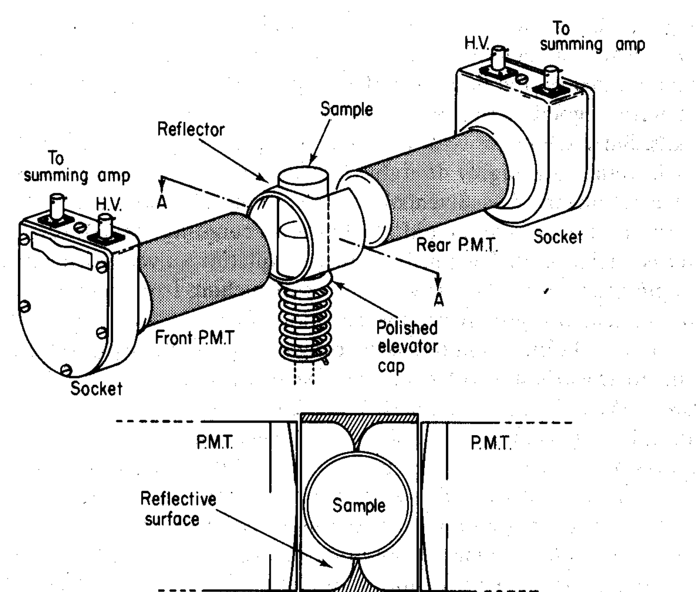


FIGURE 18.1 Photo Multiplier Tubes

Typically, the LSC uses three (energy) channels. The lowest is commonly set for tritium, the center for mid-range beta emitters such as ^{14}C or ^{35}S and the highest energy channel is often an open window or high energy beta emitters such as ^{32}P. A timer controls the duration of the count for the sample. The computer handles data analysis such as quench correction and background subtraction.

Fluorescence quenching is the main problem to deal with in a LSC. This is a process that reduces the light output that would normally be expected. There are five different quenching that may occur (chemical, dilution, color, oxygen and self-quenching). The most common two are chemical and optical.

When the sample being counted contains atoms that trap some of the emitted energy and release it as thermal energy rather than light it is called chemical quenching. Color quenching involves absorption of some of the light before it leaves the solution. Many samples, such as urine, contain molecules that strongly absorb certain wavelengths of light thus degrading the signal. The quenching problem is handled by measuring the amount of quenching and applying a “quench correction” to the counter results. Manufacturers can provide calibrated quench standards.

Section 19. USE OF FUME HOODS AND GLOVE BOXES

LEARNING OBJECTIVES:

STATE three types of airborne hazards where fume hoods are effective.
STATE two types of physical hazards where fume hoods are effective.
IDENTIFY what the air circulation is called that takes place around a fume hood.
DEFINE face velocity.
IDENTIFY the minimum distance from the front of a fume hood where experiments should be performed.
IDENTIFY the reasons and criteria for using a glove box.
IDENTIFY 5 components of a glove box.

INTRODUCTION

Many of the materials used in laboratories give off fumes, mists, vapors, particulates and aerosols that are hazards. To minimize exposure to these materials special precautions, need to take. In many laboratories this often means working within a fume hood or working with a glove box.

A. WHY LABORATORY HOODS ARE NEEDED

The most efficient and cost-effective form of contaminant control is local exhaust ventilation. This involves capture of the chemical contaminant at its source of generation. The laboratory chemical fume hood is a specialized form of capture hood that totally encloses the emission source.

Hoods are necessary for controlling possible airborne contamination arising from work with radioactive materials. The airflow into the hood must be adequate, and the hood must be designed such that the lines of airflow are all directed into the hood and away from the operator. Airflow into the hood should be between 100 and 125 linear feet per minute when the hood sash is at its normal open position during use. A recommended opening is 14 inches to give eye protection as well as effective ventilation. Flows above 125 feet per minute may lead to turbulence and some release of hood air to the laboratory.

Even the best hoods do not completely isolate the area inside the hood from the laboratory, so there is a limit to the maximum amount of activity that can be handled. Careful solutions can be processed that contain up to 100 mCi of the less hazardous beta emitters in the hood without serious contamination to personnel or surroundings. However, if complex wet operations with risk of serious spills, or dry and dusty operations must be performed, a completely isolating system such as a glove box may need to be used. If massive shielding is needed, a more elaborate system such as a hot cell is required.

Provisions should be made for HEPA filters and/or activated charcoal absorbers to be installed at the hood air outlet when required by NRC regulations. The fan should be selected to handle the increased static pressure produced by the air filtration system.

B. PROTECTIONS AFFORDED BY FUME HOODS

The simplest type of confinement and enclosure may be accomplished by limiting the handling of radioactive materials to well-defined, separated areas within a laboratory, and by the use of sub-isolating units such as trays. For low-level work where there is no likelihood of atmospheric contamination this may be sufficient. If the possibility exists of the release to the atmosphere, either as a gas or an aerosol, of amounts of activity between 1 and 10 times the maximum recommended body burden, the usual practice is to use a ventilated hood.

- HEPA filters have unique characteristics.
  - Disposable, dry-type filters
  - Constructed of Boron Silicate microfibers
  - Be able to capture particles as small as 0.3 of a micron with 99.9% success rates.
- Remember: HEPA filters do not guard against hazardous “gases”.
  If substances give off both particles and gases talk to a supervisor or the Radiation Safety Officer about the proper hood to use.

- When working with radioactive material, a radioisotope hood should be used which:
  - Is impermeable to such materials.
  - Will minimize dangerous exposure.
- No matter what sort of hood is being used, and what precautions are taken, things can still go wrong.
  - It is important to "be prepared" for accidents.
  - Spills need to be dealt with immediately.
  - Follow the facility's clean-up procedures.
  - Soak up spills with absorbent materials.
  - Dispose of resulting residues properly.
- Small fires can also occur in hoods.
  - If possible, put out fire with extinguishers or through suffocation.
  - If uncontrollable, close the sash and evacuate.
  - Sound alarms and call for assistance, if needed.
- Ventilation failures can also occur with hoods which:
  - Can be caused by malfunctions in electrical lines.
  - May result in the release of harmful fumes, vapors or particles.

C. HOW HOODS FUNCTION MECHANICALLY

The function of hoods may be studied by using the chemical exhaust hood as an example. They:

- Prevent contaminants within the hood from entering the "breathing zone".
- Create a protective barrier by pulling air into and through the hood.
- "Inward" airflow keeps hazards from escaping.

Captured contaminants are filtered, diluted and exhausted through a duct system.

Hoods can also provide protection from "physical" threats.

The sash protects workers from hazards such as chemical splashes, sprays, fires and minor explosions.

To make sure they are operating safely, hoods are thoroughly at several junctures:

- When first installed.
- Whenever a change is made in the lab's ventilation system.
- Periodically throughout the year.

D. TESTING HOODS FOR CORRECT OPERATION

Factors to consider when choosing a performance test include (1) reason for testing, (2) type and quantity of chemicals or biological agents to be used in hood, (3) types of operations and equipment to be used in hood, (4) number and type of users, (5) diversification of hood use, both in the short term (months) and long term (years), (6) location of hood within the facility, (7) type of hood (conventional or auxiliary air), and (8) ease of performance of test.

Performance tests involve measurement of the hood flow characteristics (face velocity and air quantity) and the efficiency of the hood in containing an artificial challenge gas or aerosol generated within the hood.

Fume hoods should be tested to verify adequate performance. Generally, this involves measurement of total volume flow and face velocity across the hood opening and comparison to design guidelines. Face velocity measurements should be made at 9 to 12 points equally distributed across the opening of the hood. In addition, observe airflow patterns made by generating a source of smoke across the face opening. It has been common practice to conduct these tests at regular intervals throughout the year on operational hoods.

There are specific steps to follow to determine if a hood is operating correctly.

Air circulation around the hood ("CROSS DRAFT") should be checked first.

- Measure six inches from the front of the hood.
- Should not be greater than 20 linear feet per minutes.

Next a smoke tube should be used to make sure airflow within the hood is correct.

- Smoke should head for the ventilation ducts.

Then measure the face velocity, the rate of air coming through the face of the hood.

- Open the sash.
- Use instruments such as anemometers or velometers.
- Do not use sheets of tissue or other paper as a substitute.

Measuring this "Face Velocity" requires great precision.

- The hood face is divided into a grid pattern.
- Velocity of the air is measured in each quadrant.
- Values for specific points can vary +/- 25%.
- No measurement should be below 60 feet per minute.

Face velocity is also compared to cross draft.

- Cross draft should never be greater than 20% of Face Velocity.

If problems are apparent, several things will be checked or adjusted:

- Interior hood baffles.
- Laboratory ventilation systems.

Checking for turbulence within a hood is also important.

- Use “smoke patterns” for this purpose.

If excessive turbulence is seen (or smoke is not captured) a number of things will be checked:

- Location of equipment within the hood.
- The hood’s Face Velocity.
- Location of air-input ports.
- Physical location of the hood itself.
- Volume of air coming into the hood.

E. PROPER USE OF LABORATORY HOODS

Hoods must be used correctly to be effective, see figures B.19.1 through B.19.4.

- Maintain proper airflow within the hood.
- Perform experiments at least six inches inside the hood.
- Elevate equipment (especially large pieces) if necessary.

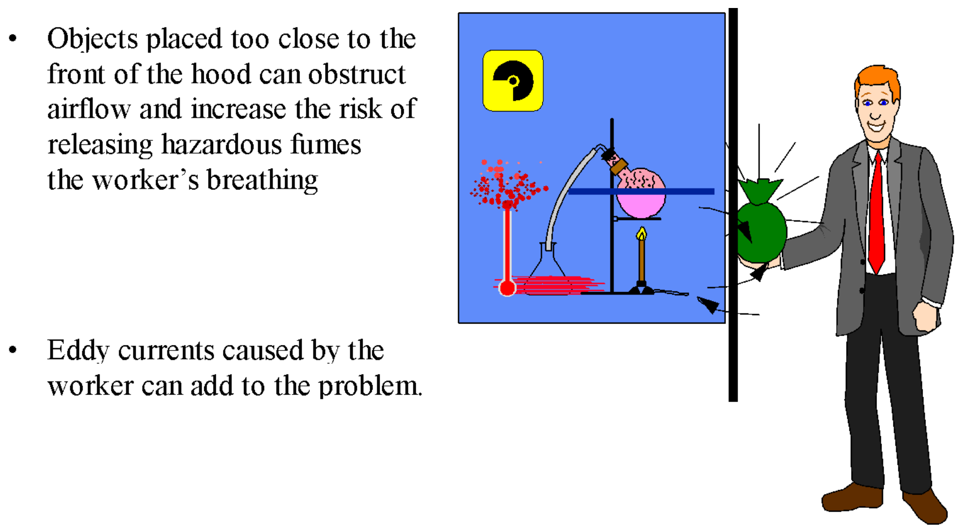


FIGURE 19.1 - PROPER USE OF FUME HOOD

- Too large an opening will reduce the hood flow to dangerously low levels.
- Air velocity will not be adequate to prevent escape of hazardous fumes.

FIGURE 19.2 - FUME HOOD SASH OPEN

- Pull the sash down as far as possible when working.
  Keep it at a comfortable level.

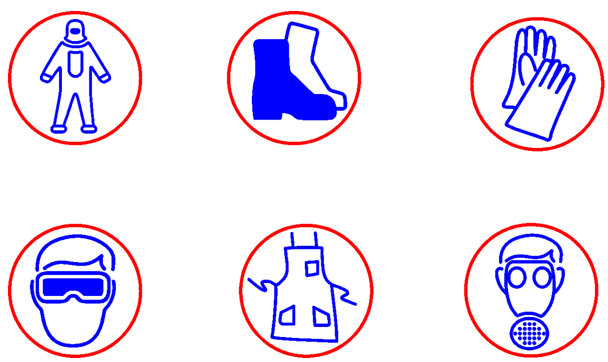


FIGURE 19.3 - PERSONNEL PROTECTIVE EQUIPMENT

- When working with a hood, personal protective equipment is still required.
  - Safety eyewear.
  - Lab coats.
  - Gloves.
  - Other protection if necessary.
- Hoods should not be used as storage cabinets.
  - Overloading restricts the airflow.
  - This can result in dangerous build-up of hazardous vapors.
  - Chemicals stored in hoods can make an emergency or fire worse.
  - When not actively working with a material in the hood, put it away.
- Take steps to prevent contaminated air in hoods from entering the laboratory.
  Keep the sash closed as much as possible.
- Pay attention to air monitors.

- Maintain hood face openings to one square foot or less at all times to keep air velocity above 100 linear feet per minute (100 lfm).

- Keep containers sealed to minimize releases.

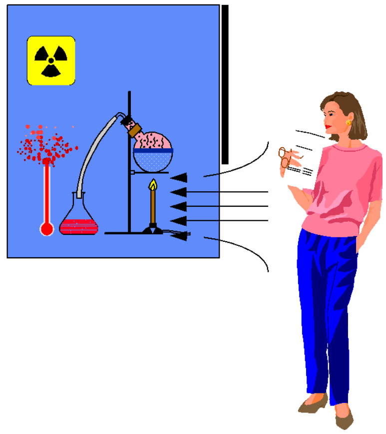


FIGURE 19.4 - FUME HOOD FACE OPENING

- It is also important to exercise caution around hoods.
  - Airflow must not be disrupted.
  - Even velocities of 100 linear feet per minute, can be overcome by rapid movements in front of the hood.
- Solid objects should be kept from entering a hood's exhaust ducts because they:
  - Can lodge in a duct or fan.
  - Adversely affect airflow.
  - Can change the filtration characteristics of the system.
- Never place your head inside an exhaust hood.
  - They disrupt airflow.
  - There is a risk of being overcome by potentially hazardous fumes/vapors.

F. WHY GLOVE BOXES ARE USED

There are two reasons to use a glove box.

1. To contain hazardous materials that are radioactive, chemically toxic, carcinogenic or a biohazard.

2. To keep oxygen and/or moisture away from material.

The need for a glove box is based on:

- Toxicity of the substance being handled.
- Quantity needed in an operation.
- Chemical nature of the substance.
- The ability to disperse the content.
- Type of work being done.

When the toxicity, radioactivity level, or oxygen reactivity of the substances under study is too great to permit safe operation in a chemical fume hood, resort must be made to a totally enclosed, controlled-atmosphere glove box must be used. The special feature of a glove box, as the name suggests, is the total isolation of the interior of the box from the surrounding environment. Items can be manipulated inside the box by means of full-length gloves sealed into a sidewall of the box. To prevent loss of materials from the inside of the glove box to the laboratory, the box is maintained under substantial negative pressure relative to the laboratory.

- What requirements do you have for a glove box?
  - Is a stainless-steel box required?
  - What type of atmosphere - air or inert?
  - Visibility and accessibility - how much?
  - Is shielding and remote handling required?
- What are the general glove requirements?

There are general requirements for specific radionuclides being handled. Tritium can be especially difficult to control. Under some chemical conditions, half of the uptake from tritium is provided by absorption through the skin. These compounds and quantities should be handled in a glove box with the appropriate support equipment installed. Basic requirements for working with tritium are given in Table 19.1 below.

TABLE 19.1

Requirement for working with tritium

Glove	**Type**	**Use**	**Change**
Inner	Cotton	Absorbs moisture	15 minutes
Second	Pylox	Second barrier	15 minutes
Third	Pylox	Third barrier	15 minutes
***	Gauntlets	Arm protection	15 minutes
Glove box glove	Butisol or Hypolon	Primary protection hand & arm	Yearly

- What special safety features should be installed?
  - A pressure drop gauge measures differential pressure between room and box or airlock. The normal range is 0.5 to 1.0 inches of water.
  - Positive gas pressure control system is present on inert boxes.
  - Some working station HEPA filtered hoods are equipped with flow indicators.
  - An alarm that is sensitive to excessive heat or heat loss.
- What utilities are needed such as lights, power or gas? Ground interrupt circuits should be installed. In some cases, explosion proof conditions need to be met.
- Ergonomics are very important. This is the person to machine interface. The set up should be specific to the individual. For example, the glove box needs to be at a

height where the operator can handle the samples and equipment inside the box with as much comfort as possible. It should not be too high or too low for the operator.

- Glove boxes must be seismically secured. In certain parts of the country, there is a significant concern that the glove box will be relocated by environmental conditions such as an earthquake.

G. BASIC COMPONENTS OF A GLOVE BOX

Basic components of a glove box (figure 19.5) are:

- Exhaust filters to capture effluent
- Intake filter to control humidity
- Heat detector
- Pressure gauge to verify direction of flow
- Bag-out port to input and exit samples, waste, and equipment
- Glove ports for manipulating samples and equipment
- Window to observe work
- Box to contain hazardous materials

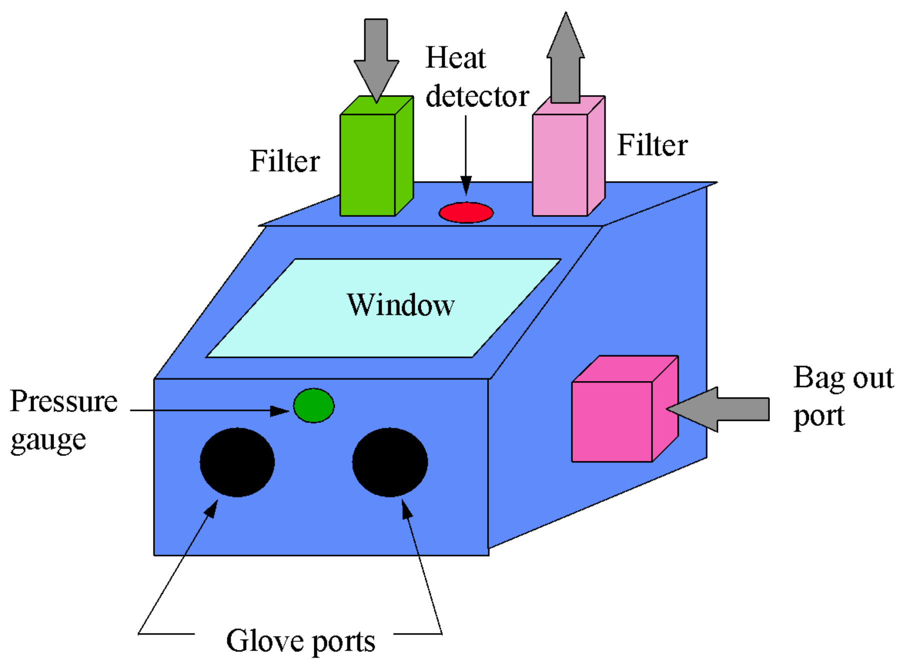


FIGURE 19.5 - COMPONENTS OF A GLOVE BOX

H. PROPER USE OF GLOVE BOXES

Always understand the procedure before starting an operation.

Perform a self-safety check.

- Is the appropriate protective clothing being worn?

- Is the operator certified to perform the work?
- Check the laboratory for:
  - Any leaks.
  - Strange noises.
- Review procedures.
- Obtain all necessary supplies.
- Check ventilation before starting.
- Check for hazards before starting work.
  - In case of atmospherically sensitive material, it is good practice to have secondary contaminant.
  - Minimize the amount of powder that could be exposed to the glove box atmosphere.
- Check status of gloves
  - Put on inner gloves.
  - Loosen the glove port cover and check for leaks.
  - Check the rolled-up glove box glove. Check the gloves for breaks as they are unrolled or untied.
  - If leaks or breaks is detected, close port and call for assistance.
- Check for puncture hazards.
  - Sharp objects could puncture glove or hand, by injecting material directly into bloodstream.
  - Hot objects could melt the glove.
  - Glass objects could be hit and broken.
- Minimize the amount of hazardous material in a glove box.
  - Package and transfer trash as it accumulates.
  - Limit quantities of hazardous materials to what is necessary.
  - Do not use glove box for unnecessary storage.
  - Use secondary containment.
- Always close out operations in a routine manner.
  - Clean up and bag-out all trash.
  - Turn off any utilities.
  - If anything is left on, notify the appropriate individuals. Also, leave a note with emergency instructions.
  - Double check that everything is off.
  - Secure the gloves and replace the glove port covers.
  - Turn off survey meter, if applicable.
  - Complete paper work as appropriate.

I. TYPES OF EMERGENCIES THAT MAY INVOLVE GLOVE BOXES

There are five basic types of emergencies which may involve glove boxes, failure of the glove, contamination incidents, excessive pressure in the glove box, excessive negative pressure in the glove box and a fire in the glove box.

1. Serious failure of glove - what to do.

a. Do not withdraw the hand.

b. Shout for help.

c. Get respirator and don.

d. When protected, withdraw hand while leaving glove in box.

e. Place contaminated hand in plastic bag until decontaminated.

f. Secure glove port cover.

g. Call for assistance in decontamination.

2. Contaminated inner glove - what to do.

a Remove glove by turning the glove inside out.

b. Check hand for contamination.

c. If contaminated, bag hand.

d. Call for assistance.

3. Personnel contamination - what to do.

a. Call for assistance.

b. Local skin contamination:

- Any methods used must not abrade skin.
- Contain the wastewater. It is considered contaminated.

c. Wound contamination:

- Do not attempt to decontaminate. Medical advice must be obtained.
- Do not stop bleeding unless it is life threatening.

4. Excessive pressure in glove box - what to do:

- Sound the alarm.
- Put on respiratory protection.
- For air box - adjust dampers to obtain proper negative pressure.
- Call for assistance.
- Exhaust filters may need changing.

5. Excessive negative pressure in a glove box - what to do:

- Shut exhaust damper.
- Adjust intake damper.
- If glove fails, respiratory protection is needed.
- Call for assistance.

6. A fire in a glove box may release hazardous material and result in:

- Loss of filtration and other controls.

- Loss of shielding.
- Emission of toxic vapors or fumes.
- Explosion.
- Electrical shock hazards.

7. **In case of fire, the primary concern is your safety.**

- Don respirator.
- Notify fellow workers and call for emergency services.
- Use extinguisher.

Section 20. STORAGE AND CONTAINMENT

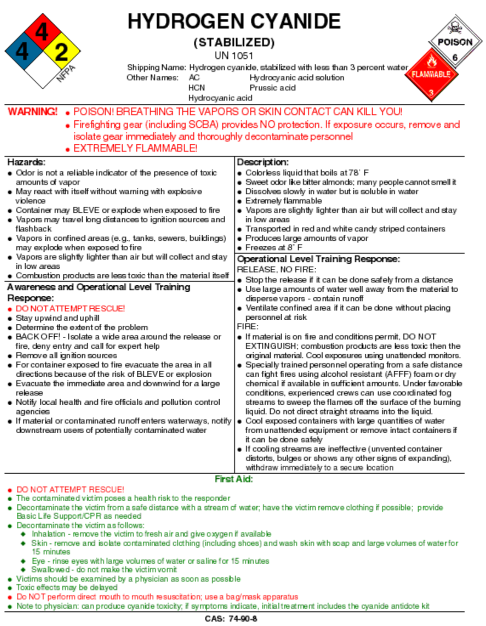
LEARNING OBJECTIVES:

DEFINE secondary containment.
STATE the general hazards' classes for storage of materials.
STATE the general guidelines for storage of hazardous materials.
DEFINE the proper storage for radioactive materials.

INTRODUCTION

This section is designed to inform the worker of storage methods for hazardous material commonly found in the general laboratory. In the general laboratory, the storage of chemicals will take priority over the concept of radioactivity.

Everything in the world is made of chemicals. Some chemicals are made by nature and some chemicals are man-made. Both natural and man-made chemicals may have hazards.



HYDROGEN CYANIDE
(STABILIZED)
UN 1051

Shipping Name: Hydrogen cyanide, stabilized with less than 3 percent water
Other Names: AC, HCN, Hydrocyanic acid, Hydrocyanic acid solution, Prussic acid

WARNING!
- POISON! BREATHING THE VAPORS OR SKIN CONTACT CAN KILL YOU!
- Firefighting gear (including SCBA) provides NO protection. If exposure occurs, remove and isolate gear immediately and thoroughly decontaminate personnel
- EXTREMELY FLAMMABLE!

Hazards:
- Odor is not a reliable indicator of the presence of toxic amounts of vapor
- May react with itself without warning with explosive violence
- Container may BLEVE or explode when exposed to fire
- Vapors may travel long distances to ignition sources and flashback
- Vapors in confined areas (e.g., tanks, sewers, buildings) may explode when exposed to fire
- Vapors are slightly lighter than air but will collect and stay in low areas
- Combustion products are less toxic than the material itself

Awareness and Operational Level Training Response:
- DO NOT ATTEMPT RESCUE!
- Stay upwind and uphill
- Determine the extent of the problem
- BACK OFF! - Isolate a wide area around the release or fire, deny entry and call for expert help
- Remove all ignition sources
- For container exposed to fire evacuate the area in all directions because of the risk of BLEVE or explosion
- Evacuate the immediate area and downwind for a large release
- Notify local health and fire officials and pollution control agencies
- If material or contaminated runoff enters waterways, notify downstream users of potentially contaminated water

Description:
- Colorless liquid that boils at 78˚ F
- Sweet odor like bitter almonds; many people cannot smell it
- Dissolves slowly in water but is soluble in water
- Extremely flammable
- Vapors are slightly lighter than air but will collect and stay in low areas
- Transported in red and white candy striped containers
- Produces large amounts of vapor
- Freezes at 8˚ F

Operational Level Training Response:

RELEASE, NO FIRE:
- Stop the release if it can be done safely from a distance
- Use large amounts of water well away from the material to disperse vapors - contain runoff
- Ventilate confined area if it can be done without placing personnel at risk

FIRE:
- If material is on fire and conditions permit, DO NOT EXTINGUISH; combustion products are less toxic then the original material. Cool exposures using unattended monitors.
- Specially trained personnel operating from a safe distance can fight fires using alcohol resistant (AFFF) foam or dry chemical if available in sufficient amounts. Under favorable conditions, experienced crews can use coordinated fog streams to sweep the flames off the surface of the burning liquid. Do not direct straight streams into the liquid.
- Cool exposed containers with large quantities of water from unattended equipment or remove intact containers if it can be done safely
- If cooling streams are ineffective (unvented container distorts, bulges or shows any other signs of expanding), withdraw immediately to a secure location

First Aid:
- DO NOT ATTEMPT RESCUE!
- The contaminated victim poses a health risk to the responder
- Decontaminate the victim from a safe distance with a stream of water; have the victim remove clothing if possible; provide Basic Life Support/CPR as needed
- Decontaminate the victim as follows:
  - Inhalation - remove the victim to fresh air and give oxygen if available
  - Skin - remove and isolate contaminated clothing (including shoes) and wash skin with soap and large volumes of water for 15 minutes
  - Eye - rinse eyes with large volumes of water or saline for 15 minutes
  - Swallowed - do not make the victim vomit
- Victims should be examined by a physician as soon as possible
- Toxic effects may be delayed
- Do NOT perform direct mouth to mouth resuscitation; use a bag/mask apparatus
- Note to physician: can produce cyanide toxicity; if symptoms indicate, initial treatment includes the cyanide antidote kit

CAS: 74-90-8

Chemicals have three main types of hazards:

- Fire
- Reactivity
- Health

Anyone working with dangerously reactive liquids and solids should always practice good personal hygiene.

- Wash hands and exposed skin before going home.

- Wash hands and exposed skin before eating, smoking or using the toilet.
- Launder work clothing regularly and separately from non-work clothing.
- Keep food, drink and cigarettes away from storage and handling areas.

A. CONTAINMENT OF MATERIAL

Containment generally means using vessels, trays, blotting paper and bench tops to contain contamination. Secondary containment means that the primary container is within another container in the event the primary container fails, such as from breaking. Secondary containers should be at least the same volume as the primary container see figure 20.1.

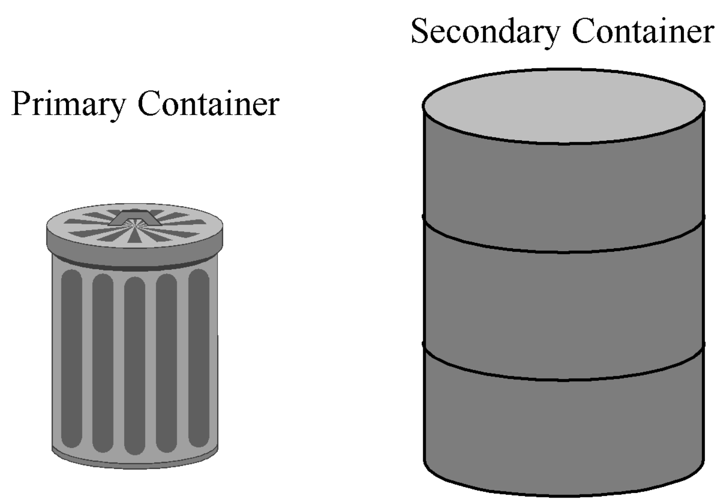


FIGURE 20.1 - DOUBLE CONTAINMENT

B. SEGREGATION AND STORAGE

Many chemicals may be dangerous, even common chemicals used every day.

1. Fire Hazards

Flammable chemicals catch fire easily. Flammable liquids produce vapors. These vapors are often heavier than air. They can sink to the floor and travel long distances through buildings. When the vapors catch fire, the fire can flash back to the container of flammable liquid. This may cause an explosion. A common type of labeling system was developed by the National Fire Protection Association (NFPA) and is depicted in figure 20.2 below.

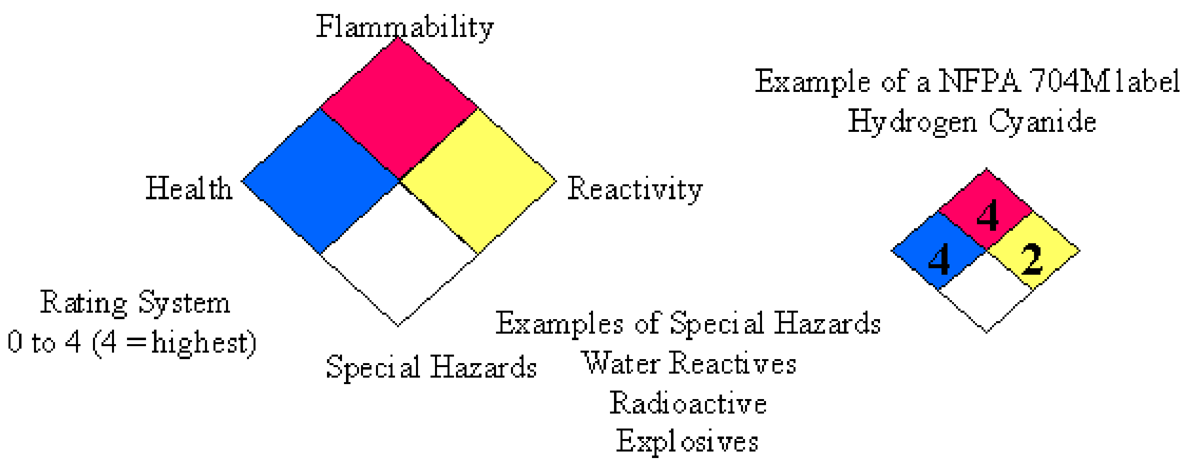


Figure 20.2 NFPA 704M Labels

Flammability hazard rating:

4 = Very flammable gases or very volatile flammable liquids.

3 = Can be ignited at all normal temperatures.

2 = Ignites if moderately heated.

1 = Ignites after considerable preheating.

0 = Will not burn.

2. Reactivity (Stability) Hazards

Reactive materials may explode and catch fire:

- If they are knocked over or dropped
- If pressure or temperature is increased
- If they mix with air, water or other chemicals

Reactivity hazard rating:

4 = Readily detonates or explodes.

3 = Can detonate or explode but requires strong initiating force or heating under confinement.

2 = Normally unstable but will not detonate.

1 = Normally stable. Unstable at high temperatures and pressure. Reacts with water.

0 = Normally stable. Not reactive with water.

3. Health Hazards

Exposure to some chemicals may result in health problems such as:

- Itchy skin
- Irritation of the eyes and nose
- Allergies
- Skin burns
- Eye damage

  Health hazard rating:

  4 = Can cause death or major injury despite medical treatment.

  3 = Can cause serious injury despite medical treatment.

  2 = Can cause injury. Requires prompt treatment.

  1 = Can cause irritation if not treated.

  0 = No hazard.

If enough of a hazardous chemical enters the body, a person may be poisoned. Symptoms can include headache, dizziness and nausea. Some chemicals may cause serious diseases. Repeated exposure to some chemicals, or exposure over a long time, may even cause serious diseases such as cancer.

Segregate incompatible materials and store them by hazard class. This will minimize the possibility of the materials reacting with each other in general storage and during emergency conditions such as fires. Recommended general hazard classes for storage are:

- **Caustics** (bases) – Corrosives are defined in terms of pH (i.e., materials with a pH $\leq$ 2 or $\geq$ 12.5). It is also defined in terms of the ability of a substance to cause visible destruction or changes in skin tissue at the site of contact or a liquid that has a severe corrosion rate on steel or aluminum. Strong acids and strong bases are corrosive.
  Upon contact, corrosives will cause immediate damage to skin or eyes, and upon inhalation will cause irritation and burning of the nose, throat, and lungs. Upon ingestion, corrosives will irritate and burn the mouth, throat and stomach. Corrosives will also generate heat due to the chemical reaction and can act as an ignition source, potentially causing a fire.

- **Acids** (mineral) – Acids are compounds that yield H^+ ions when dissolved in water. Chemicals ending with "ic" are acids 100 percent of the time. Common industrial acids include acetic, nitric, hydrochloric, and sulfuric acids. "Concentrated" and "dilute" refer to the concentrations in solution. Mixing a concentrated acid with enough water will produce a dilute acid.
  The acidic nature of a given solution is characterized by its pH, where pH is the negative logarithm of the molar H^+ concentration ($-\log[H^+]$). A solution with pH < 7 is acidic, a solution with pH 7 is neutral, and a solution with pH > 7 is basic (basic/alkaline/caustic).

- **Flammables** (including organic acids) - Flammable is the most common hazard class. Most solvents are flammable and catch on fire easily. Skin contact with flammables usually causes irritation and defatting. Inhalation of vapors usually causes dizziness and headaches. The flashpoint of the chemical determines if the chemical is flammable or combustible. The NFPA diamond uses a four –quadrant diamond to display the hazards of a material. See figure 20.2 above. The top quadrant (red) contains the flammability information in the form of numbers ranging from 0 to 4. Materials designated 0 will not burn. Materials designated 4 rapidly or complete vaporize at atmospheric pressure and ambient temperature; will burn readily (flashpoint <73 °F and having a boiling point < 100 °F).

- **Poisons** (toxic) – These are substances that must enter the body to cause injury or illness. Usually, only a small amount of material is necessary to cause the injury or illness. The extent of injury depends on the route of exposure, the concentration or strength of the chemical, and the length of exposure time.

- **Oxidizers** – Oxidizing agents often have "per" prefixes (perchlorate, peroxide, permaganate) and often end in "ate" (chromate, nitrate, chlorate). Oxidizing agents are generally recognizable by their structures or names. They tend to have oxygen in the structures and often release oxygen as a result of thermal decomposition. Strong oxidizers have more potential incompatibilities than perhaps any other chemical group (with the exception of water reactive substances). It is safe to assume that they should not be stored or mixed with any other material except under carefully controlled conditions.

  Oxidizers give off oxygen and promote the combustion process in other materials, and are a fire hazard (i.e., an acetylene torch cannot cut steel with adding oxygen). Oxidizers increase the hazard of a material catching fire. They can make flammable extremely flammable, and they make many corrosives act like flammables. They are very reactive and can cause burns similar to corrosives. They can also bleach the skin and hair.

- **Water reactive** – These are chemicals that react violently when mixed with water. Often heat and other energy is released quickly.

- **Explosives** – These are mater5ials that can react very rapidly, releasing a lot of energy within a very short period of time. Flammables can act like explosives, depending on the container it is in. They are extremely difficult to protect against since they are not detectable. You cannot fight explosions, but you can prevent them from occurring.

C. GENERAL GUIDELINES

Chemical incompatibility can manifest itself in many ways, with combinations resulting in fires, explosions, extreme heat, evolution of toxic gases, and polymerization. Keep flammables by themselves in approved storage cans or cabinets.

- Keep acids away from bases.

- Separate organics from inorganic.
- Store oxidizers away from flammables.
- Provide as much physical separation as possible between classes.

Biohazards should be properly labeled and may be stored as one group.

- Class A and B carcinogens should be properly labeled and stored with their chemical family.
- Store Class C carcinogens in the glove box or another regulated area.

D. STORAGE AREAS

Store large bottles and containers close to the floor.

Shelves should:

- Secured (bolted) to a wall
- Have lips or restraining cords to prevent bottles from falling

Storage area should be well lit, properly ventilated, and have an even temperature.

Secondary containment of chemical containers in polyethylene trays is recommended for spill protection.

E. FORMATION OF ORGANIC PEROXIDES

Organic peroxides are a class of compounds that has unusual stability problems. This makes them among the most hazardous substances found in the laboratory. As a class, organic peroxides are considered to be powerful explosives and are sensitive to heat, friction, impact, and light, as well as to strong oxidizing and reducing agents. Common compounds that form peroxides during storage include:

- ethyl ether
- isopropyl ether
- potassium metal
- vinyl chloride
- cyclohexene
- dicyclopentadiene
- vinyl acetylene
- dioxane
- acetal
- butadiene
- vinyl ethers
- styrene
- diacetylene
- vinyl acetate
- tetrahydrofuran
- divinyidene chloride
- cumene

- sodium amide
- methyl acetylene
- methylcyclopentene

F. STORAGE OF RADIOACTIVE MATERIALS

Radioactive materials must be properly stored. They must not be stored in the same room with chemical waste. Below is a list of guidelines for the storage of radioactive materials.

- Store in unbreakable containers. If not possible, use secondary containment.
- Use stable containers with secure means of closing.
- Keep away from sinks and drains or other possible pathways.
- Protect them from adverse environmental factors.
- Keep away from combustibles and other fire sources.
- Ensure protection from “unauthorized relocation”.
- If more than 100 times the ALI is handled, contaminant should be resistant to fire.
- Clearly label outside of container with contents especially if stored overnight.
- Provide instructions to open containers.
- Separate waste from usable radioactive materials.
- Monitor storage locations for possible contamination frequently, especially when storing tritium.

Section 21. RADIOACTIVE WASTE MANAGEMENT

LEARNING OBJECTIVES:

DEFINE how waste should be segregated.
STATE where radioactive waste should be stored.
STATE how sharps should be handled.
IDENTIFY methods of waste minimization.
IDENTIFY the various waste disposal methods and their controls.
EXPLAIN waste volume reduction techniques.
IDENTIFY mixed waste and the appropriate disposal methods.

INTRODUCTION

This unit is designed to inform the worker of waste control concepts. It will also present methods used to minimize radioactive waste.

Radioactive waste management is an important aspect of radiological protection. Using proper control practices will help ensure a safe working environment and minimize exposure to workers and the environment. It is important for all employees to recognize waste management techniques to keep exposures as low as possible and to minimize cost.

A. SEGREGATION

Segregate waste by type to facilitate storage, waste minimization and disposal. Waste is segregated to prevent fires, explosions, spills, reactions, and other events that potentially endanger human health and the environment. Waste segregation requires constant attention and monitoring. Proper waste segregation is heavily emphasized in regulations and is a common focus of inspections.

B. WASTE STORAGE

Each laboratory should have a designated location in which to store waste. Radioactive waste should be stored separately from hazardous waste. This location should be out of the way of normal lab activities, but easily accessible and recognizable. The waste accumulation area is a temporary location for waste until it can be picked up by waste processing staff for storage, treatment, or disposal.

Waste materials should be kept in secondary containers and segregated by hazard class. The waste must be properly labeled. Secondary containers may be lab trays or any device that will contain 110% of the largest container.

Check for:

- Properly completed label (activity, quantity, date).
- Proper containment (integrity).
- Waste separated in the appropriate containers (shielding, capped).
- Waste separated by type and radionuclide (half-life, liquid, animal).

Containers should always be arranged so that labels are visible without having to move the container. Containers showing signs of leakage or deterioration are addressed immediately. Secondary containment for liquids waste must be adequate (at least 100 per cent of the initial volume). Documentation and record keeping are needed for disposal and license inventories.

C. SHARPS

Contaminated syringes, glass pipettes and other sharp items must be placed in a specifically designed, rigid container. This minimizes the risk to laboratory personnel and those individuals processing waste.

D. MINIMIZE WASTE GENERATION

- Confine operations with radioactive materials to as small an area as possible.
- Minimize materials introduced into radioactive material handling areas. Restrict materials entering areas where unsealed radioactive materials are handled to only the materials needed for the performance of work.
- Segregate clean materials from radioactive materials. Do not dispose of clean materials in radioactive waste containers. This may seem like it is obvious, BUT it takes extra effort to remove labels from materials such as clean packing boxes, etc.
- Reserve an assortment of tools and supplies primarily for use in contamination areas.
- Contamination control measures such as covering benches generate waste. On the other hand, decontamination generates a great deal of waste. Good housekeeping,

minimizing bench areas and secondary containment can reduce the amount of coverings required.

E. STORAGE FOR DECAY

- **Storage**: Some radionuclides have a short half-life and can be stored for decay. Generally, radionuclides with a half-life less than 90 days are stored separately. These are decayed between 7 to 10 half-lives. They are then surveyed and disposed as non-radioactive waste.
- **Substitution**: Substitute for shorter-lived radionuclides if possible, i.e. ^{33}P for ^{35}S.

F. DISPOSAL VIA SANITARY SEWER

Some regulatory agencies allow for discharge via sanitary sewer. NRC licenses allow limited quantities of radionuclides to be disposed via the sanitary sewer per 10 CFR 20.2003. Many businesses do not allow for such discharge due to other liability issues.

In general, only tritiated wastes are released to the sanitary sewer. Other isotopes are released, but only under the direct supervision of the Radiation Safety Officers for those facilities. No radioactive liquids are released to the sanitary sewer without the written permission of the Radiation Safety officer. The Radiation Safety Officer shall maintain accurate and complete records on all releases to the sanitary sewer system, and shall ensure that regulatory guidelines are not violated.

There are limits that are authorized to be released into the sanitary sewer specific to each radioisotope via 10 CFR 20.2003. Most states have adopted the same limits within their respective regulations. Some local governments impose more restrictions of sanitary sewer disposal of radioactive materials.

G. DISPOSAL VIA FUME HOOD

Most regulatory agencies allow for discharge via exhaust fume hoods. These limits are also dictated as to the limits via 10 CFR 20.2003. Most states have adopted the same limits within their respective regulations.

H. DISPOSAL OF SPECIFIC WASTE PER 10 CFR 20.2005

Safety in transport of radioactive materials is accomplished mainly by requiring the proper type of packaging, depending upon the type, quantity and form of the material. Waste generators and waste processors must record on shipment manifests a description of the transferred waste, and must also carry out a quality control program to assure that classification of waste is carried out in a proper manner. The manifest must also indicate as completely as practicable: a physical description of the waste, the volume, radionuclide identity and quantity, the total radioactivity, and the principal chemical form. The solidification agent must be specified. Additional information may be required for shipment to a particular disposal facility depending upon facility specific license conditions.

In accordance with Part 20.2005, NRC licensees may dispose of the following without regard to its radioactivity:

- Liquid scintillation counting media containing 0.05 microcuries or less of ^{3}H or ^{14}C per gram of medium

- Animal carcasses containing 0.05 microcuries or less of ^{3}H or ^{14}C per gram of animal tissue averaged over the weight of the entire animal

I. MIXED WASTE

Mixed waste is exceedingly difficult if not impossible at this time to dispose of. Currently there are no commercial disposal sites accepting mixed waste. Mixed waste is defined as hazardous chemical waste banned from land burial and is radioactive.

1. Ways to avoid generating mixed waste

a. Use non-hazardous cleaning materials for decontamination whenever possible.

b. Segregate radioactive waste from other hazardous waste at the source.

c. Explore the use of other materials that are non-hazardous for use in radiological areas to prevent the generation of mixed waste.

d. Discontinue use of non-biodegradable (organic solvent based) liquid scintillation fluid. Organic scintillation fluids create a mixed waste disposal of which may not be possible.

2. Other methods of facilitating disposal:

a. Do not combine solvents with metals. Disposal is very difficult. Examples are lead or mercury combined with solvents.

b. Generally, it is a good idea to separate organic and inorganic waste whenever possible.

J. VOLUME REDUCTION

Radioactive waste cost is directly related to the volume. Chemical waste cost is based upon the weight of the chemicals being disposed. Radioactive waste is based upon volume. Reduction techniques will significantly reduce cost.

1. Compacting

Compacting may produce reduction factors of 5 to 1. Only dry solid waste (primarily laboratory trash) may be compacted. Liquids, animals, and solids (such as machinery) cannot be compacted.

2. Shredding

Shredding may produce reduction factors of 12 to 1. Plastic vials and other materials with a memory can be effectively reduced in volume by shredding. This technique removes the memory.

3. Incineration

Incineration is difficult under present regulation and political climate. This method would be effective for many types of radioactive waste. Obtaining permits and going beyond public opinion is the most difficult aspect of incineration operations.

Section 22. ANIMAL FACILITIES

LEARNING OBJECTIVES:

IDENTIFY what training, if any, is required for animal handlers.
IDENTIFY what areas should be surveyed when handling animals and radioactive materials.
STATE the appropriate posting of animal facilities and equipment.
IDENTIFY methods used to prepare the workstation where animals are handled.
IDENTIFY the proper handling of specimens.
EXPLAIN the method of labeling cages.
STATE the methods of waste disposal and storage of animal carcasses.

INTRODUCTION

This section is designed to inform the worker of sources of radioactive contamination when working with animals and for the animal handler. It will also present methods used to control the spread of contamination.

A. TRAINING OF ANIMAL HANDLERS

All persons who work with animals that have received radioactive materials, through injections or infusions, are required to be trained in areas of radiation safety.

Protocol studies involve specials procedures and require special training relative to the procedures. Different animals also require different procedures based upon the needed animal handling techniques. The animal handler should be experienced with the specific animal types and techniques before introducing radioisotopes.

If researchers are required to wear personnel dosimeters, such as film badges during animal experiments, the animal handlers may need dosimeters as well. Personnel dosimeters are not necessary for all work with radioactive materials. For example, they are inappropriate for ^{3}H and ^{14}C. Internal dosimetry may be a special concern in the event of animal bites.

1. Laboratory Practices

a. Do not eat, drink, chew gum, apply cosmetics, or store food in areas where radioactive materials are utilized.

b. All personnel need to wash hands immediately after completion of any procedure that utilizes radioactive materials.

c. Animal rooms containing radioactive materials shall be marked with the radiation-warning symbol and shall be kept locked when unattended.

d. Each cage should be individually labeled with the radioactive warning symbol.

a. All procedures shall be in accordance with the established protocol and written facility safety guidelines.

2. Personal protective clothing

Personal protective clothing shall be worn when working in rooms containing radioactive materials and experimental animals:

- Regular work clothes and footwear without open toes
- Disposable shoe coverings
- Laboratory coat or coveralls
- Personal exposure monitors as appropriate for the isotopes and amounts in use
- Gloves and booties
- Safety glasses

B. MONITORING, SURVEYING AND POSTING

Monitoring for radioactive contamination should be conducted after each experiment involving the use of radioisotopes according to the method prescribed by the facility. Caging and lab surfaces with the potential to be contaminated must be monitored prior to release. Areas contaminated to a level in excess of two times background must be decontaminated. Records of caging and monitoring must also be provided to the animal facility manager.

- The room in which the animal receives the radioactive material and the room in which the animal is housed afterwards must be posted with a “CAUTION RADIOACTIVE MATERIALS” sign.
- If radioactive materials are not going to be used again in the near future, closeout surveys of the rooms should be performed and the signs removed.
- Geiger counters or G-M meters are used to look for gross contamination of certain high-energy beta and some gamma emitting radionuclides.
- Use meter to check hands, shoes, clothing, floor, bench and cage.
- Use wipes and count in a liquid scintillation or gamma counter for contamination check to determine counts or disintegrations per minute.
- All cages housing or transporting radioactive animals must be labeled “CAUTION RADIOACTIVE MATERIAL,” with the radionuclide, activity, and date indicated.

- Cages must be monitored and decontaminated, and labels must be removed before the cages are sent to the cage wash area or are released for general use. Never use cages that have not been decontaminated for other use because there is a danger of exposures to other staff.

C. WORKSTATION PREPARATION

1. Absorbent paper

a. Absorbent paper must be placed underneath the animals throughout the radioactive injection or infusion procedure.

b. Cages used to transport and house the animals must be lined with absorbent paper.

c. If it is likely that the animal will excrete on the floor in the housing area, absorbent paper should also be placed under the cage.

d. All soiled absorbent paper must be disposed of as radioactive waste.

2. Booties

a. If it is likely that the floor will become contaminated during the radioactive procedure, it should be covered with absorbent paper, and disposable booties should be worn to prevent tracking of the contamination.

b. Booties must be disposed of as radioactive waste before leaving the potentially contaminated area.

3. Labeling of specimens

a. Any specimens collected from the animal after it has received radioactive materials must be labeled “CAUTION RADIOACTIVE MATERIAL”.

b. If the specimen is to be taken to another room, double containment must be used.

c. Depending on the type and quantity of radioactive material in the specimens, shielding may be needed.

4. Radioactive waste disposal

a. Collection and disposal of excreta

1) Animal excreta must be collected and disposed of as radioactive waste.

2) The excreta should be collected and sealed in plastic bags using absorbent material like absorbent paper or animal bedding.

3) The bags must be packaged in medical pathological waste containers.

4) The box must be labeled “CAUTION RADIOACTIVE MATERIAL” and a tag indicating the radionuclide, activity, and date must be attached.

b. Disposal of animal carcasses

1) Remove all intravenous lines, needles and absorbent paper and dispose of them separately, before packaging carcasses for disposal.

2) The needles and other sharps must be placed in a separate labeled plastic box.

3) Carcasses must be sealed in a leak proof plastic bag.

4) Carcasses must be refrigerated if stored for 4 hours.

5) Carcasses must be frozen if stored for 24 hours or more.

5. Necropsy

If an animal dies unexpectedly after receiving an injection or infusion of radioactive material and a necropsy is needed, coordinate with Radiation Safety personnel.

Section 23. GAMMA-CELL IRRADIATORS

LEARNING OBJECTIVES:

STATE who may use the irradiator and what training they must have.
STATE the types of monitoring performed when using gamma-cell irradiators.
DEFINE the expected dose rates to the operator of gamma-cell irradiators.
EXPLAIN the emergency procedure to be followed.
STATE how to obtain authorization to use gamma-cell irradiators.
EXPLAIN the responsibilities of the custodian and the user.

INTRODUCTION

This section is designed to inform those who work with gamma-cell irradiators that are commonly used in general laboratories. Gamma-cell irradiators are designed to provide a large uniform gamma field for irradiation of samples.

For radiation protection purposes, external dose shall be the primary concern of the operator when using the gamma-cell irradiation.

A. DOSE RATES ASSOCIATED WITH GAMMA-CELL IRRADIATORS

Gamma-cell irradiators provide a large gamma dose to samples. The most common radioisotopes used are ^{60}Co or ^{137}Cs. The sources are sealed sources, normally comprised of stainless-steel encapsulation. Due to the encapsulation, only the gamma radiation is emitted.

Sources are commonly provided as a line source, similar in shape to a pencil. Within a sample chamber, this shape enables the exposure to be provided as a uniform dose over a larger distance. A point source projects the dose differently, as radiation coming from a single small point. When the distance from a line source is increased (about three times the length of the source) the line sources act as a point source. The exposure to the operator would be considered a point source due to the distance from the source itself.

The containment vessel of the system is normally heavily shielded, typically with lead. The dose rate on the outside of most systems, approximately one foot from the source, is normally 2.5 mR/hr or less when the source is in the expose position. This is the highest potential for an exposure of the operator. When the source is in the safe position, the source is more heavily shielded. When the system is in the expose position, the level of exposure to the operator, one foot from the source calculated for a working year would not exceed the regulatory limit of a whole-body exposure to gamma radiation.

2.5 mR / hour x 40 hour / week x 50 weeks / year = 5,000 mrem / year

Or (50 mSv) / year

Routinely, the operator is only at this location for a few minutes at any one time. The systems are designed with interlocks and other safety features to minimize any potential exposure to operators. These are designed to move the source into the safe position if the chamber is opened or other situations arise. Commonly the system is designed with alarms in the room to detect the changes in the system and exposure rates. The system includes visible and audible alarms. Administrative controls are established to make sure the area is clear and ensure that the operators have the appropriate training. This control normally includes control of the key to the system. Workers using the system must be monitored for whole body gamma exposures.

B. MONITORING

Check to be sure that the area radiation monitoring system, normally mounted on the wall adjacent to the gamma-cell irradiator unit, is operating as evidenced by an audible clicking (background radiation) and lighted panel.

Ensure that the portable radiation monitor is operational by performing the pre-operational checks for the instrument. Place the portable radiation monitor on the floor near the door of the irradiator in the "ON" position. This is a secondary check for potential exposures to the operator in the form of an area monitor.

Ensure that whole-body dosimeter is worn. Do not enter without proper dosimetry.

C. SYSTEM OPERATION

Ensure that the interlocks are operational according to the instructions posted in the room. Verify that the source is in the "OFF" position before attempting to open the chamber door. After placing the sample into the chamber, recheck the interlocks again before placing the source in the active position.

After using the irradiator, document in the Irradiator Safety Manual Use Log that interlock checks have been completed in accordance with the Health Physics instructions posted for the equipment.

The operator should stay behind the designated point, normally identified on the floor, or outside the room when the unit has the source in the active position. If the sample will be left in the irradiator for an extended period of time while operator is not attending the system, a notification should be posted. In the event of a problem with the system, there will be a point of contact to evaluate system failures and to return any samples left in the system.

Never leave the unit or room unlocked or unsecured!

D. EMERGENCY PROCEDURES

In the event of malfunction during loading, unloading or use of the irradiator or if the wall-mounted radiation monitor should give an alarm signal, the unit is to be taken out of service immediately. Evidence of malfunction includes binding or moving parts, the presence of metal shavings or chips, or any abnormal condition or functions. **IN NO CASE SHOULD THE USER ATTEMPT TO REPAIR OR MODIFY THE IRRADIATOR!**

- Log and describe any abnormal occurrences in the use log.
- Should the "RELEASE SOURCE" fail, an audible alarm will be triggered in a short period of time, typically 10 seconds. Should this alarm sound, leave/secure the room and immediately contact the Radiation Safety personnel.
- If at any time it is possible to open the cavity door without pressing the door release button, the interlock assembly is malfunctioning. DO NOT USE THE UNIT! Lock it with the padlock, leave/secure the room and contact Radiation Safety personnel.

- If at any time it is impossible to raise the source with the door closed or to open the door with source in the “OFF” position, either the interlock switches or interlock solenoids are malfunctioning. DO NOT USE THE UNIT! Lock it with the padlock, leave/secure the room and contact Radiation Safety personnel.

E. PROCEDURES FOR GAINING AUTHORIZATION FOR USE

Irradiators are used under the supervision of individuals so authorized by the Radiation Safety Officer, Radiation Safety Committee or the Radiological Control Manager. Those individuals are commonly referred to as the “Irradiator Custodians.”

An individual may become an Irradiator Custodian by submitting the appropriate request to the organization that manages or oversees the Radiation Safety Program.

Typically, what is included in the request is:

- Evidence of meeting the training requirements for such sources.
- Specific information about the irradiator: location, source strength, operating procedures, others who will be supervised during such use.

Typical Irradiation Procedures:

- The irradiator may ONLY be operated by the custodian (individual responsible for supervision of use, approved by name under the Radiation Safety Program) or by his/her designees (previously approved individuals).
- Users must be familiar with the operating instructions and adequately trained in the proper operation and emergency procedures specific to the unit.
- Obtain the key from the custodian.
- Place the key in the unit, and turn it on.
- Place samples to be irradiated into the chamber, then actuate “Irradiate” position.
- At the end of the irradiation period, be sure the source(s) are in its shielded position, then remove the irradiated samples.
- Record the required information in the Use Log.
- Secure the irradiator, and return the key to the custodian.

F. TRAINING REQUIREMENTS

The custodian must:

- Completion of basic Radiation Safety with an emphasis on biological effects with gamma sources and external monitoring of exposures.
- Demonstration of the proper operation of the specific irradiator to be authorized.
- The exposure rates for the unit or system to be authorized and how to perform the appropriate calculations for dose estimates (primarily for the samples to be irradiated).
- Emergency procedures for the unit or system.

G. RESPONSIBILITIES

1. The custodian must:

a. Maintain the irradiator in a clean and mechanically functional condition.

b. Notify the Radiation Safety personnel of any anticipated changes in configuration, location or operation in a timely manner.

c. Ensure that designated users receive training as required.

d. Ensure that designated users wear whole body radiation monitors when operating the irradiator.

e. List and certify designated users.

f. Ensure physical security of the key to the unit and prevent unauthorized use of the irradiator.

g. Notify the Radiation Safety personnel immediately of any malfunctions or problems with the irradiator.

h. Arrange for repairs or maintenance of the unit by appropriate persons.

2. Designated Users must:

a. Operate the unit in accordance with the established procedures at all times.

b. Wear a whole-body radiation monitor when operating the irradiator.

c. Notify the Custodian and the Radiation Safety personnel of any malfunctions or other problems with the irradiator.

d. Ensure that the key is returned to secure storage following irradiation.

3. Radiation Safety Branch/Personnel must:

a. Maintain the license/authorization issued to the facility by regulatory agency for operation of the irradiator.

b. Conduct leak tests and other safety inspections as described by the manufacturer and the regulatory agency.

c. Provide the appropriate training.

H. SYSTEMS CONTROLS

1. Installation

Relocation of an irradiator shall be permitted only after authorization is granted by the regulatory agency. The request normally includes:

a. A description of the new facilities, including an annotated sketch of the floor plan of the room and adjoining areas, showing the planned location of the irradiator and identifying the types of activities to be conducted in the adjoining areas. Adjoining areas include rooms and corridors surrounding the room as well as above and below the room.

b. A description of the security measures to be taken to prevent unauthorized access to the irradiator.

c. Verification that the floor of the proposed facility is rated to support the weight of the irradiator. Sufficient evidence may be obtained and submitted.

d. A description of the methods to be utilized in moving the irradiator.

2. Change of Custodian

If the transfer of responsibility for the irradiator is contemplated, then new applicant must apply for authorization.

3. Removal

If removal of decommissioning of the irradiator is contemplated, contact the regulatory agency. The irradiator can only be transferred to another appropriately licensed institution or individual. In the event that the sealed source(s) are to be disposed, the manufacturer or others who are appropriately licensed must be involved in their removal and disposition.

4. Maintenance

a. In the event of malfunction of the irradiator, the custodian shall be responsible for notifying the internal regulatory authority (typically the Radiation Safety Manager).

b. Under no conditions shall irradiator operators or the custodian attempt to:

- Repair or modify source positioning mechanisms, shutters, interlocks, shielding or other systems designed to maintain the irradiator in a safe condition.
- Attempt to gain access to or remove the sealed source.
- Replace the source.
- The manufacturer or a licensed agent may (only) perform maintenance procedures.

I. OTHER SAFETY PROCEDURES

The Radiation Safety Manager will be responsible for ensuring that leak tests are performed. Personnel under direction of the Radiation Safety Manager will perform leak tests on the sealed sources at intervals not to exceed 6 months. Any leak test indicating 0.005 μCi or more of removable contamination shall result in the immediate removal from service of the irradiator. Notification will be made to the appropriate authorities as required by regulation. The performance of the leak tests shall be recorded in the Use Log.

The Radiation Safety Manager will be responsible to ensure routine compliance surveys are performed at least semi-annually, such as:

- Checking for proper operation of all interlocks on the irradiator.
- Measuring exposure rates at all accessible points around the irradiator using a portable ionization chamber, and ensuring that radiation levels are within regulatory limits.
- Checking for compliance with provisions of the irradiation operating procedures, including adherence to the proper training of users.
- Documenting completion of survey in the Use Log.

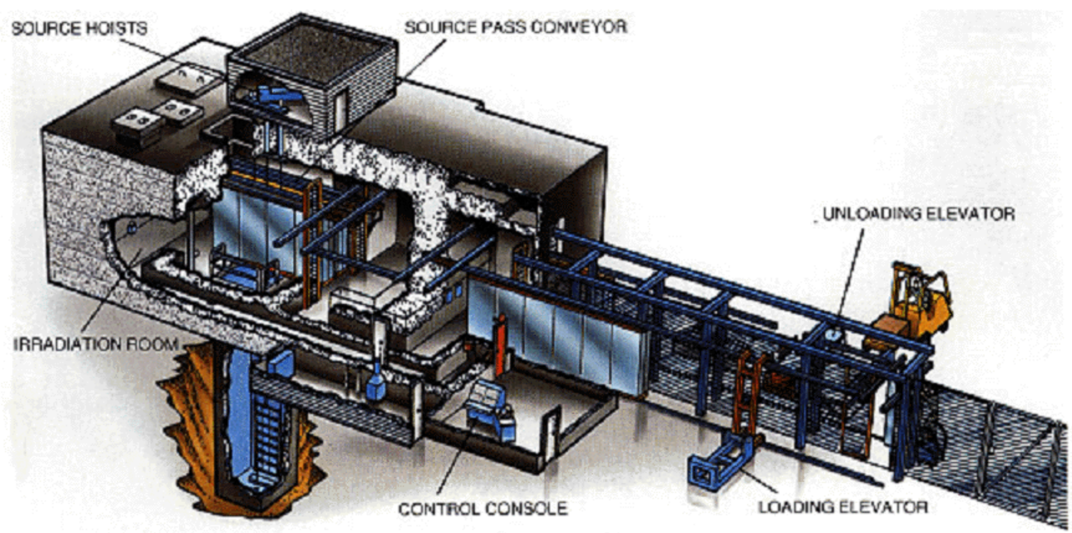


Figure 1: JS-8900 Unit Carrier Irradiator

Section 24. SEALED SOURCES

LEARNING OBJECTIVES:

DEFINE the process for determining if a sealed source is accountable or exempt.
STATE the frequency for performing an inventory and leak check for sealed sources.
STATE the actions if a source listed on the inventory cannot be accounted for.
STATE the wipe activity level at which action must be taken by the individual performing the leak check.
IDENTIFY the type of hazard presented by sealed sources.

INTRODUCTION

What is a sealed source? A sealed source is a radioactive material that is contained in a sealed capsule, sealed between layers of non-radioactive material, or firmly fixed to a non-radioactive surface by electroplating or other means. The confining barrier prevents dispersion of the radioactive material under normal and most accidental conditions related to the use of the source. In a general laboratory a sealed source can be calibration sources, check sources, internal standards, plated sources or irradiators. They are generally gamma emitters. However, some plated sources are beta emitters such as ^{63}Ni used in gas chromatography.

The inventory and leak testing of radioactive sources is a federally regulated process. The process begins and the paper trail for the source starts when the source is requested for purchase. Once the source has been received and classified the source custodian will add the source to the inventory.

A. GENERAL HAZARD

Sealed sources are primarily an external hazard. They present an exposure potential to individuals close to the source. They are used in a variety of ways from gas chromatography to calibration sources. Sources are used to check portable survey meters, personnel survey devices (both portable and fixed), and counting instruments. These sources are used to verify that the instruments are operating properly.

They should always be handled as if they were contaminated materials (i.e. gloves, remote handling tools). There are four basic means of protection with sealed sources:

- **Time** — The less the time the less the exposure.
- **Distance** — The exposure rate is reduced by $1/D^2$ (point source).
- **Shielding** — Absorption of the radiation will reduce the dose.
- **Source Reduction** — Dose rate is directly proportional to the source activity.

Radiographers to check welds at construction sites also use large radioactive sealed sources. These sources present significant exposure potential such as this recent case study.

In 2002, the Nuclear Regulatory Commission was notified of an overexposure to an individual conducting industrial radiography. A radiographer had been exposed to an uncollimated, 1295.0 GBq (35 Ci) cobalt-60 source while conducting industrial radiography at a temporary job site. The radiographer was conducting radiography inside a vessel at a fabrication shop. At 4:00 a.m. the radiographer entered the vessel to reposition the source for another exposure. After returning to the camera to crank out (extend from the shield) the source for the next exposure, the radiographer discovered that the source had not been retracted into the shielded position within the exposure device. The radiographer reported that his pocket dosimeter was off scale and that his occupational dosimeter had inadvertently fallen from his belt while waiting in the truck between exposures. The radiographer indicated that he could not hear his alarm ratemeter because of the background noise and that he failed to use a survey meter before entering the vessel. A dose estimate of 0.7 Sv (70 rems) whole-body was based on the radiographer's estimation that he was inside the vessel for no more than 30 seconds. The licensee has referred the radiographer for medical follow-up studies. This dose is 14 times the allowable limit for one year. He/she can no longer being employed as a radiation worker for at least 14 years.

B. SOURCE CLASSIFICATION

A sealed source is defined as radioactive material that is contained in a sealed capsule, sealed between layers of non-radioactive material, or firmly fixed to a non-radioactive surface by electroplating or other means. The confining barrier prevents dispersion of the radioactive material under normal and most accidental conditions related to use of the source.

C. ACCOUNTABLE SOURCES

Accountable radioactive sources are sealed sources with an activity level equal to or greater than values listed in Table 24.1 below:

1. Exempted Sources

An exempt source is a sealed source with a half-life of less than 30 days or an activity less than the sources for radionulcides listed in Table 24.1.

2. Inventory

Sealed sources must be inventoried on some routine frequency. Most facilities are required to perform the source inventory at least every 6 months. Larger sources and specific radioactive materials must be inventoried every 3 months.

3. Inventory Process

The inventory process not only determines if the source is in the proper location but verifies such things as:

a. Proper labeling and identification

b. Source isotope, activity, and date activity was determined

TABLE 24.1

Values for Exemption of Sealed Sources from Inventory

Less than 300 μCi

^{3}H	^{55}Fe	^{113}Cd	^{180}Ta
^{7}Be	^{59}Ni	^{115}In	^{181}W
^{14}C	^{63}Ni	^{123}Te	^{185}W
^{35}S	^{73}As	^{135}Cs	^{187}Re
^{41}Ca	^{79}Se	^{141}Ce	^{204}Tl
^{45}Ca	^{87}Rb	^{152}Gd	
^{49}V	^{99}Tc	^{157}Tb	
^{53}Mn	^{107}Pd	^{171}Tm	

Less than 30 μCi

^{36}Cl	^{105}Ag	^{145}Pm	^{175}Hf
^{40}K	^{114m}In	^{147}Pm	^{181}Hf
^{59}Fe	^{113}Sn	^{145}Sm	^{179}Ta
^{57}Co	^{119m}Sn	^{151}Sm	^{184}Re
^{75}Se	^{121m}Sn	^{149}Eu	^{186}Re
^{84}Rb	^{123}Sn	^{155}Eu	^{192}Ir
^{85}Sr	^{123m}Te	^{151}Gd	^{193}Pt
^{89}Sr	^{125m}Te	^{153}Gd	^{195}Au
^{91}Y	^{127m}Te	^{159}Dy	^{203}Hg
^{95}Zr	^{129m}Te	^{170}Tm	^{205}Pb
^{93m}Nb	^{125}I	^{169}Yb	^{235}Np
^{95}Nb	^{137}La	^{173}Lu	^{237}Pu
^{97m}Tc	^{139}Ce	^{174}Lu	
^{103}Ru	^{143}Pm	^{174m}Lu	

Less than 3 μCi

^{10}Be	^{93}Zr	^{121m}Te	^{166m}Ho
^{22}Na	^{94}Nb	^{129}I	^{176}Lu
^{26}Al	^{93}Mo	^{134}Cs	^{177m}Lu
^{32}Si	^{95m}Tc	^{137}Cs	^{172}Hf
^{46}Sc	^{97}Tc	^{133}Ba	^{182}Ta
^{44}Ti	^{98}Tc	^{144}Ce	^{184m}Re
^{54}Mn	^{106}Ru	^{144}Pm	^{185}Os
^{60}Fe	^{101}Rh	^{146}Pm	^{194}Os
^{56}Co	^{102}Rh	^{148m}Pm	^{192m}Ir
^{58}Co	^{102m}Rh	^{148}Eu	^{194m}Ir
^{60}Co	^{108m}Ag	^{150}Eu	^{194}Hg
^{65}Zn	^{110m}Ag	^{152}Eu	^{202}Pb
^{68}Ge	^{109}Cd	^{154}Eu	^{207}Bi
^{83}Rb	^{126}Sn	^{146}Gd	^{210m}Bi
^{88}Y	^{124}Sb	^{158}Tb	^{241}Cm
^{88}Zr	^{125}Sb	^{160}Tb	

Less than 0.3 μCi

^{90}Sr	^{178m}Hf	^{226}Ra	^{249}Bk
^{113m}Cd	^{182}Hf	^{228}Ra	^{254}Es
^{138}La	^{210}Po	^{241}Pu	

Less than 0.03 μCi

^{146}Sm	^{210}Pb	^{242}Cm	^{257}Fm
^{147}Sm	^{236}Np	^{248}Cf	^{258}Md

Less than 0.003 μCi

^{148}Gd	^{238}U	^{241}Am	^{247}Bk
^{228}Th	^{237}Np	^{242m}Am	^{249}Cf
^{230}Th	^{236}Pu	^{243}Am	^{250}Cf
^{232}U	^{238}Pu	^{243}Cm	^{251}Cf
^{233}U	^{239}Pu	^{244}Cm	^{252}Cf
^{234}U	^{240}Pu	^{245}Cm	^{254}Cf
^{235}U	^{242}Pu	^{246}Cm	
^{236}U	^{244}Pu	^{247}Cm	

Less than 0.0003 μCi

^{227}Ac	^{232}Th	^{248}Cm	^{250}Cm
^{229}Th	^{231}Pa		

D. LEAK TESTING OF SEALED SOURCES

Sources must also be leak tested to determine if the encapsulation is still intact. No sources are allowed to show leakage of more than 0.005 μCi (in the US). If the levels of removable contamination are not in excess of the required standards, the unit will be allowed to remain in service until the next leak test.

1. Precautions for Leak Testing

a. A sealed source shall not be removed from its container solely for the purpose of leak testing if it could produce a whole body dose rate of greater than 100 mrem/hr, unless the source can be removed remotely.

b. An exemption from leak testing may be granted if the source custodian prepares a letter describing the situation, and concurrence has been obtained from the regulatory agency. The source shall then be leak tested the next time it is removed from its container.

c. Sources in storage for periods longer than 6 months, need only to have their integrity determined when they are removed from storage and before being placed in use.

2. Leak Test Performance

To determine if the source is leaking, the surface of the source or the inner surface of the container must be smeared and counted on instruments capable of detecting activity below the established limit.

3. Determining the Wipe Activity

Count the source and container wipes to determine if the sealed source is leaking.

4. Report Unsatisfactory Leak Test Results.

E. CALCULATING THE SOURCE ACTIVITY OR DOSE RATE

The dose rate is determined to warn the user of the hazards associated with source. The dose rate as determined by an actual meter reading or estimation is recorded. The dose rate and activity calculations can be accomplished in one of several ways.

1. Calculating the dose rate: Use the 6CEN Rule.

The dose rate expected from the source at 1 foot may be approximated using the D=6CEN rule if the activity and isotope are known. This formula can only be used for gamma energies greater than 0.07 MeV, but less than 2 MeV.

D = (6) (C) (E) (N) where:

D	=	dose rate in R/hr at 1 foot
(6)	=	conversion constant (5.91 rounded up to 6)
(C)	=	activity of the source in Curies (3.7×10^{10} Bq)
(E)	=	total gamma energy (MeV)
(N)	=	gammas per disintegrations

Example: A 100 μCi ^{137}Cs (3.7×10^{2} Bq) source equals what dose rate at 1 foot? The energy of ^{137}Cs gamma's is 0.662 MeV and is produced 85 percent of the time during decay.

D = (6) (C) (E) (N)

D = (6) (1 E-4) (0.662) (0.85)

D = 3.38 E-4 R/hr or 0.3 mR/hr at 1 foot.

The activity of the source can be determined using this formula if the dose rate at one foot is known and isotopic content of the sources is known:

$$C = \frac{D}{(6)(E)(N)}$$

Example: A ^{137}Cs source with a 1foot dose rate of 1.5 mR/hr contains approximately how many Curies of activity?

$$C = \frac{1.53E-3}{(6)(0.662)(0.85)} = 4.44E-4 \text{ Ci}$$

2. Decay corrected activity method: To determine the current activity of a source, the following information must be known:

- The original source activity
- Source isotopic content
- Date the original activity was determined

Once all the information is known use the following formula to calculate the current source activity:

$$A = \frac{A_0}{2^n}$$

Where: A_0 = original activity

A = activity left after n half lives

n = elapsed time ($T_{1/2}$)

elapsed time = time elapsed between the original source activity determination and the current date in the same units as the $T_{1/2}$

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

Example: A 100 µCi ^{60}Co source was manufactured on 1/1/81, what will the source activity be as of 1/1/89? The $T_{1/2}$ for 60Co is 5.271 years.

A_0 = 100 µCi

A = ?

n = 8 years/5.271 years

$$A = \frac{100}{2^{1.52}} = 34.87 \text{ µCi}$$

The calculations must now be documented for each of the sources.

Section 25. X-RAY SOURCES

LEARNING OBJECTIVES:

IDENTIFY the dose rates produced by various x-ray producing equipment and the time required to sustain sever damage from these units.
IDENTIFY which senses can or cannot detect an x-ray beam.
IDENTIFY three ways to reduce exposures to patients and the operator from medical x-rays.
LIST two short-term effects from very high exposures to x-rays.

INTRODUCTION

This section is designed to inform the worker of sources of radiation exposure from x-ray sources. It will present methods used to control such exposures. All radiation producing machines must be registered with the regulatory agency.

A. CHARACTERISTICS OF X-RAYS

X-rays are produced when high-speed electrons are slowed down and/or stopped. Electrons are emitted from the cathode when it is heated with an electric current. The electrons are accelerated through an electric potential of several kV to several MV, and then stopped instantly in a high atomic number metal target anode, some of the kinetic energy can be converted to high-energy photons called bremsstrahlung radiation (breaking radiation). Most of the kinetic energy is converted to heat.

For electrons incident on a thick target, the fraction F of energy converted to x-rays is approximately:

$$F = 7 \times 10^{-4} Z E_k$$

Z is the atomic number of the target, and is the accelerating voltage in MV (E_k). Therefore, a 1 MV electron beam accelerated to a tungsten (Z = 74) target will be about 5 percent efficient in the production of x-rays.

$$F = 7 \times 10^{-4}\ 74 \times 1 = 0.052 \text{ or } 5.2 \text{ percent}$$

The other 95 percent of the kinetic energy of the electrons is converted to heat.

The penetrating ability of x-rays depends on their energy and the absorber. Higher energy x-rays penetrate much further than low energy x-rays.

Radiation safety concerns include:

- Sources of x-rays from external hazards (i.e., generators).
- Highly collimated and intense source of radiation emitted.
- X-rays may scatter and not be where expected. X-rays can turn corners.

- X-rays are not detected by the five senses.
- X-rays may be produced in machines designed for other purposes (i.e., shunt regulators on high voltage supplies).
  Analytical x-ray machines may produce dose rates in excess of 100,000 rad/min (1000 Gy/min). These present a significant hazard to the operator.

Details of incidents:

- Injury from placing fingers in sample chamber, most commonly from diffraction x-ray systems.
- Replacement of leaded glass with ordinary glass.
- Improper survey for x-ray leakage.
- Working in enclosures with beam "ON" because of interlock bypass.
- Hand in the beam area with the beam on.

X-rays are an external hazard. They can penetrate large distances and reach organs deep in the body. There are several primary means of protection.

Time

Distance

Shielding

X-rays systems also present an electrical shock hazard due to the high voltage.

Most Radiation Safety Programs Include:

- **Engineered Controls** - Interlocks, shields, mazes, barriers, shutters
- **Administrative Control** - Training, procedures, manuals, signs, lights
- **Monitoring** - Area, personnel, x-ray safety box, radiation detectors, fail-safe light.

No safety device is to be bypassed or inactivated without written authorization. This includes:

- Interlocks
- Safety boxes
- Shutters
- Warning lights
- Monitoring equipment

B. X-RAY SAFETY FOR MEDICAL PERSONNEL

Table 25.1 contains estimated patient doses obtained by being in the primary beam. The operator of medical systems should not be in the primary beam. Assuming that they are not and that the facility is properly designed, the operator should receive very little exposure, if any. These conditions may be different when handling animals in research environments. Often the technician must hold the patient or film cassette during exposures. This may occur if the patient is unstable or moves a great deal such as with an animal or very young child.

TABLE 25.1

Active Marrow Dose Per Examination in mrem (mSv)

Skull	78 (0.78)
Chest	10 (0.1)
Thoracic spine	247 (2.47)
Lumbar/lumbosacral spine	400 (4)
Upper GI	535 (5.35)
Barium enema	875 (8.75)
Dental	9 (0.09)

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1. Considerations for decreasing the dose from x-rays to the patient and the operator:

a. There are three general technique factors that affect the dose:

   Time - Determines the total dose received.

   Voltage - Determines the penetration of the x-rays.

   Current - Determines the dose rate.

b. Proper filtration removes the unwanted low-energy x-rays from the primary beam. This is called hardening the beam.

c. Proper collimation limits the beam to a useful area that should be as small an area as possible (of clinical interest). The intent is to keep the patient from being exposed to x-rays that are not shown on the x-ray film. Areas that are outside the film will provide no useful benefit or information.

d. High speed image receptor provides the shortest time possible that will still provide image quality desired for diagnosis. A film that responds faster requires less radiation exposure.

e. Patient screening will minimize exposures to specific audiences. Protection of the embryo/fetus is given special consideration.

f. Specialized shielding for sensitive organs like the lens of the eye, gonads and thyroid is used to minimize dose to these organs. The lens of the eye is of concern because the dose is accumulative. Gonads, bone marrow, and other organs with rapidly dividing cells are radiosensitive. These shields must be used properly to be effective.

g. Orientation of the beam should be directed to minimize exposure to everyone.

h. The maximum permissible x-ray leakage is limited by federal standards.

I. Periodic checks are performed on the x-ray system to ensure safety features are functional and provide the maximum protection to the patient and the operator.

j. Shielded enclosures are provided to minimize exposure to the operator.

k. Patients should be held only if available restraining devices are inadequate. If a patient is to be held, it is preferred that a relative hold the patient, not the operator. Law prohibits the x-ray technician from holding the patient. The relative will only be performing this activity infrequently. An operator will be exposed to enough radiation (in surgery, fluoroscopy and while doing portable x-rays) while performing routine duties. If an animal is the patient, consideration should be given to anesthesia.

l. A quality assurance program is implemented to ensure that the system (including the film development processor) is operating at its optimal performance. This will minimize retakes of the radiographs.

m. Technique factors are established for the procedure to be taken and adjusted for the x-ray system.

2. Personnel monitoring and dose limits

Whole body monitors must be worn by the x-ray technician and not by the patient. The patient is receiving an intentional exposure. The monitors are worn outside of routine clothing between the collar and waist. The custom at most facilities is to wear them under any protective equipment such as lead aprons, although some facilities wear them over the equipment.

If procedures will involve high potential doses to the extremities, additional monitoring devices will be required, such as ring badges or eye monitors.

C STRUCTURAL SHIELDING

The shielding is designed to protect against the useful x-rays, leakage radiation, and scattered radiation. Structural shielding may be either a lead-lined box in the case of an x-ray tube used by radiobiologist to irradiate small organisms, or it may be the shielding around a room in which a patient is undergoing radiation therapy. The structural shielding is designed to protect people in an occupied area outside an area of high radiation intensity. The structural shielding requirements for a given installation are determined by:

1. The maximum kilovoltage (energy) the system operates.
2. The maximum milliamperes (current) of the beam (current).

3. The workload (W), which is measured of the systems use. For x-0ray shielding design, workload is usually expressed in units of milliampere-minutes per week.
4. The use factor (U), which is the fraction of the workload during which the useful beam is pointed in the direction under consideration.
5. The occupancy factor (T), which is the factor by which the workload should be multiplied to correct for the degree or type of occupancy of the area in question. When adequate occupancy data are not available, the values for T given in Table 25.2 may be used as a guide in planning shielding.

The roentgen is used as the measure of exposure (1 R = 2.58 x 10^{-4} C/kg). Some of the physical factors that determine the shielding requirements for protection from x-ray beams are shown in figure 25.1 below. The beam is directed at the patient. The beam passes through the patient and is attenuated (absorbed) to an acceptable level by the primary barrier before irradiating "Employee-1." The leakage radiation and the scattered radiation are attenuated to an acceptable level by the secondary barrier before reaching "Employee-2".

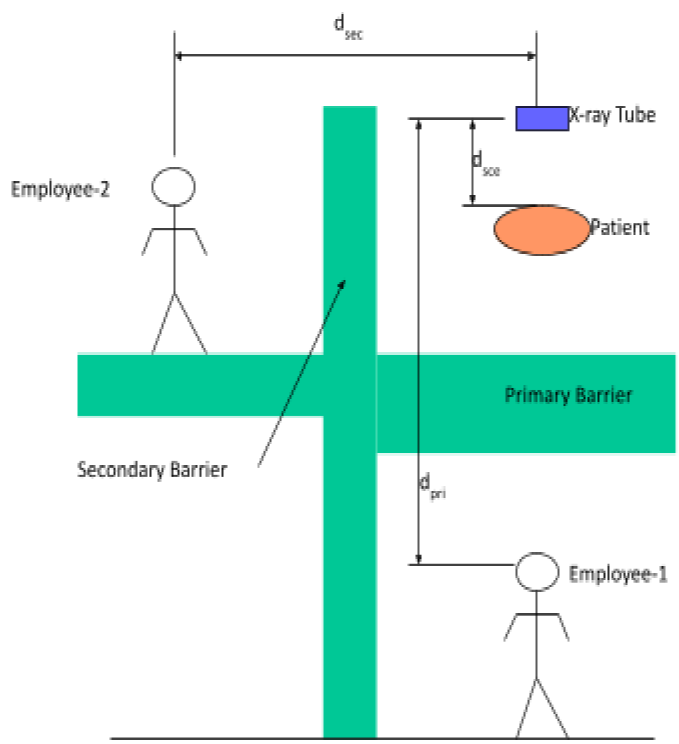

FIGURE 25.1 STRUCTURAL SHIELDING DESIGN

TABLE 25.2 OCCUPANCY FACTORS

Full occupancy, T = 1	Control space, wards, workrooms, darkrooms, corridors large enough to hold desks, waiting rooms, restrooms used by occupationally exposed personnel, children's play area, living quarters, occupied space in adjacent buildings
Partial occupancy, T = 1/4	Corridors too narrow for desks, utility rooms, rest rooms not used routinely by occupationally exposed personnel, elevators using operators, and uncontrolled parking lots
Occasional, T = 1/16	Stairways, automatic elevators, outside areas used only for pedestrians or vehicular traffic, closets too small for future workrooms, toilets not used routinely by occupationally exposed personnel

The maximum exposure rate at any occupied point at a distance "d" meters from the target in the x-ray tube is given by:

$$X_m = (P/T) \text{ R/week}$$

Where P is the maximum permissible weekly exposure (0.1 R/week for controlled areas and 0.01 R/week for uncontrolled areas) and T is the occupancy factor. Using the inverse square law, we find the radiation field to have an exposure rate at 1 meter from the target that is given by:

$$X_1 = (d^2 \text{ x } X_m) = (d^2P/T) \text{ R/week at 1 meter}$$

This exposure is due to the workload WU mA-minutes per week. This gives the following ratio:

$$K = \frac{X1}{WU} = \frac{d2P}{WUT} \; \frac{\text{R/mA-min}}{\text{week}} \text{ at 1 meter}$$

This measure is for broad beams of x-rays of various energies that have been transmitted through lead or concrete shields of varying thicknesses. The transmission of x-rays though thick shields has been found experimentally to depend mainly on the highest energy photons in the beam, and for a beam of any given minimum wavelength, to be influenced relatively little by the quality of the beam (that is, the half-value layer for that beam). To design the primary protective barrier, the value of K is computed and the required barrier thickness is read from the appropriate experimental data graphed.

D. ANALYTICAL X-RAY SYSTEMS

Two basic types of analytical x-ray systems are recognized: Open beam and enclosed beam. In the enclosed beam system, as the name implies, the x-ray beam path (both primary and diffracted beams) are completely enclosed and cannot be broken by any part of the body during normal operation.

Because it is much safer, an enclosed beam system should be selected over an open beam system whenever feasible. An open beam system is acceptable only if an enclosed beam system is impractical due to such operational requirements as:

- A need for frequent changes of attachments and configurations.
- A need for making adjustments with the x-ray beam energized.
- Motion of specimen and detector over wide angular limits.
- Examination of large or bulky samples.

1. Common Features:

- A conspicuous fail-safe light must be installed near the x-ray tube housing to indicate when x-rays are on (or present).
- Every accessory to the equipment (e.g. powder diffraction camera) must include a beam stop.
- Shielding must be provided for tube housing leakage and scattered radiation.

2. Open Beam Only

- Each port of the x-ray tube housing must be provided with a beam shutter.
- All shutters must be provided with a conspicuous “SHUTTER OPEN” indicator of fail-safe design.
- Whenever the accessory setup is not permanent (i.e. subject to change frequently or periodically as is the case with powder diffraction cameras), the beam shutter must be interlocked with every accessory apparatus coupling or collimator, such that the port will only be open when the collimator or coupling is in place.
- Shutters at unused ports should be secured to prevent casual opening.
- Exposure rates adjacent to the system must not exceed 2.5 mR/hr.

3. Enclosed Beam Only

- The sample chamber door must be interlocked with the x-ray tube high-voltage supply or a shutter in the primary beam so that no x-ray beam can enter the sample chamber while it is open.
- Radiation leakage measured at 5 cm from any outer surface must not exceed 0.5 mR/hr during normal operation.

Even though the beam is very small, its intensity is very high (500 rads (5 Gy) per second at the sample and 10,000 rads (100 Gy) per second at the x-ray tube window). A few minutes handling a sample with the beam on could cause ulceration that can only be treated by amputation. The dose rate can be calculated by:

$$R\ (\text{rad / sec}) = 50 \times \text{voltage (kV)} \times \text{Current (mA)} \times Z / [r\ (\text{cm})]^2 \times 74$$

For example, the dose rate at 2 cm from a copper target operated at 20 kV and 100 mA is:

$$50 \times 20\ (\text{kV}) \times 100\ (\text{mA}) \times 29 / [2\ (\text{cm})]^2 \times 74 = 9750\ \text{rad / sec}$$

An x-ray facility (medical) will have heavier shielding where the primary beam is directed. Both the primary and secondary beam must be shielded. The control booth is also shielded. The x-rays in the room must be reflected at least twice before entering the control booth. See figure 25.2 for an example of an x-ray room for a medical facility.

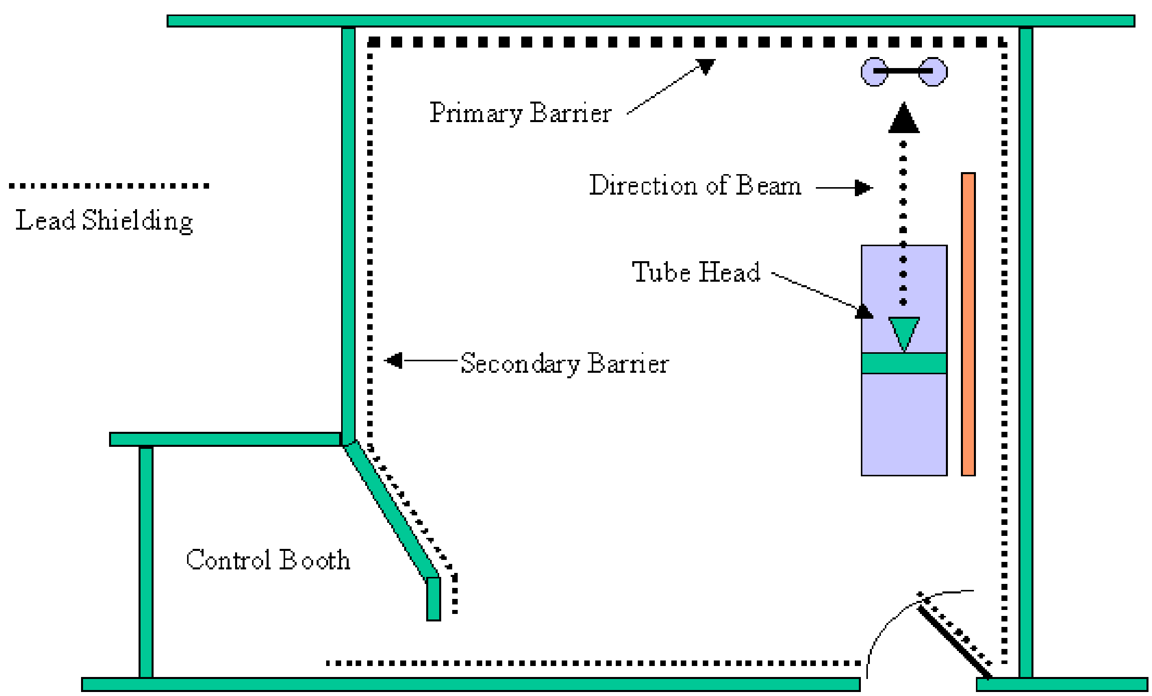

FIGURE 25.2 X-RAY ROOM FOR TYPICAL MEDICAL FACILITIES

E. Cabinet x-ray Machines

Cabinet x-ray machines are enclosed, self-shielded, interlocked cabinets. The machine can only operate when the opening is securely closed. The exposure levels at every location on the exterior meets the level specified for uncontrolled areas. Do not operate a machine if the interlocks appear to be malfunctioning. Operators must be trained in the proper operation of the system.

F. Electron Microscopes

Because of their design and operating voltage, electron microscopes do not normally present a radiation hazard. Operators do not need personnel dosimeters. Electron microscopes should not be modified in any way to increase the radiation output or reduce the shielding. Microscopists who use uranium salts when examining biological specimens should observe usual chemical precautions.

G. BASIC X-RAY SAFETY REQUIREMENTS

1. Shielding/Barriers

- X ray machines shall be designed with shielding or barriers (or both) so that personnel do not exceed regulatory dose limits.
- Dose equivalent rates around analytical x-ray machines should not exceed 0.25 mrem/hr.
- All beams with exposure rates that exceed 0.1 R/hr shall be completely enclosed.
- All ports of an analytical x-ray machine shall be covered with a radiation shield when not in use.

2. Interlocks

- Protective enclosures that are used to prevent access to x-ray beams shall be interlocked during normal operations.
- X-ray safety interlocks shall be of a fail-safe design.
- Enclosures for flash x-ray machines shall be interlocked to prevent access or entry while the high-voltage system is charged or is being charged. This system shall be designed so that the high voltage system is grounded automatically if an interlock is opened.
- Rooms or facilities used as x-ray enclosures shall have emergency shutdown ("run-safe") switches. These switches shall be labeled (clearly), their numbers and placement shall be reviewed by Radiation Safety personnel.

3. Warning Signs

- A CAUTION sign shall be posted at the room entrances or in the facility where x-ray machines are operated to indicate that high levels of radiation can be produced by equipment in this area.
- A CAUTION sign must be posted at the x-ray machine enclosure, or in the immediate area of the machine to indicate high levels of radiation can be produced by the equipment inside the enclosure.
- An approved operating procedure should be posted on or next to all x-ray machines to indicate the maximum unshielded dose rate and maximum operating parameters at which the machine is approved to operate.

4. Key Control

Machines with key-controlled consoles shall have the key removed and secured when the machine is left unattended.

5. X-Ray Surveys

- The appropriate x-ray survey/monitoring instruments shall be available to survey the x-ray machine.
- Before and after each use, x-ray survey instruments should be checked to ensure that they operate properly. Check sources or field-test jugs should be used to check the instruments.
- The Radiation Safety personnel and/or the responsible individual (or a designated qualified operator) shall perform radiation surveys every six months. These surveys shall cover all accessible areas of the x-ray machine, including the control panel and all used and unused ports. The responsible person shall document the survey results and maintain one copy on file in the log.
- A radiation survey shall be performed by qualified Radiation Safety personnel and the responsible person (or a designated qualified operator) whenever any modifications that may affect x-ray production, shielding, or safety (e.g. higher tube current, new machine location, or different or nonstandard accessories).

6. Interlock Checks

- Interlocks shall be checked at least once every six months to ensure that they function properly. Qualified operator and Radiation Safety personnel or facility electronics personnel (or both) shall perform these checks in accordance with written interlock check procedures. The responsible individual shall keep two copies of the interlock checks and the check procedures, one on file and another in the log next to the x-ray machine.
- Interlocks that malfunction shall be repaired and re-tested by a responsible individual before the machine can be operated.

7. Personnel Monitoring

- All personnel operating analytical x-ray machines shall be on a monthly monitoring program
- Finger rings. Extremity dosimetry (e.g. finger rings) should be used for the following operations if they are performed while the x-ray machine is energized:
  - Sample changing
  - Beam alignment
  - Target changing
  - Open beam operations
  - Interlock bypass operations