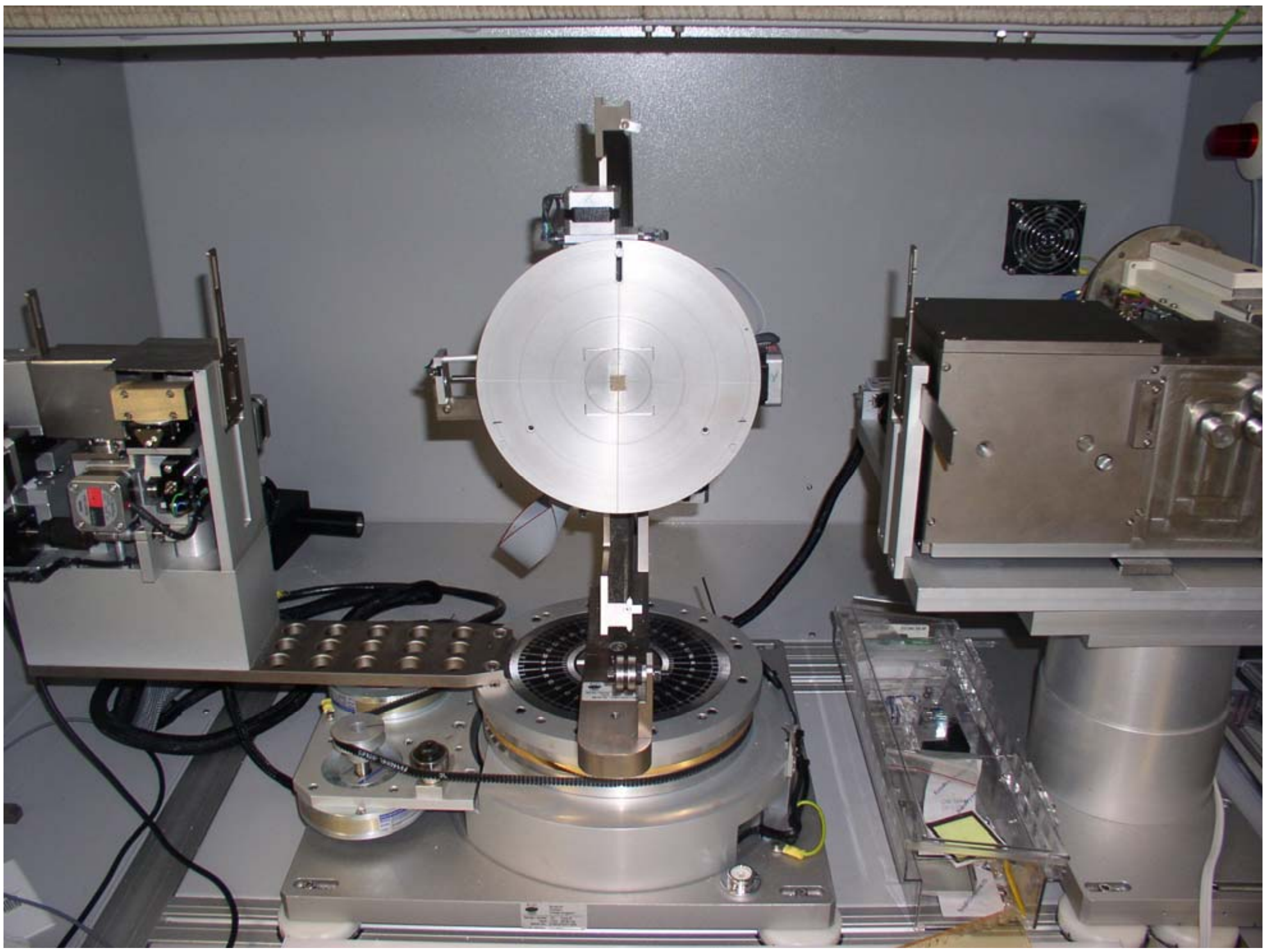
TEXAS STATE UNIVERSITY
SAN MARCOS

RADIATION SAFETY



X-RAY OPERATOR TRAINING

RMS-008

Feb 15, 2007

TEXAS STATE UNIVERSITY SAN MARCOS

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CHAPTER 1 - RADIATION PROTECTION PRINCIPLES

A. OBJECTIVES

i. Chapter Objective.

Upon completion of this unit, the participants should understand basic radiation protection principles essential to the safe operation of X-ray devices.

ii. Objectives.

Following self-study and/or classroom review, the participants will be able to:

1. Define ionizing radiation.
2. Identify sources of natural and manmade background radiation.
3. Define the Texas Department of State health Services dose limits.
4. Describe the ALARA principle.
5. List the four methods by which external exposure is reduced.

B. ATOMS

The atom, the basic unit of matter, is made up of three primary particles: protons, neutrons, and electrons. Protons and neutrons are found in the nucleus of the atom; electrons are found orbiting the nucleus. Protons have a positive charge; neutrons are neutral; electrons have a negative charge. The configuration of electron shells and the number of electrons in the shells determine the chemical properties of atoms.

C. IONIZATION

An atom usually has a number of electrons equal to the number of protons in its nucleus so that the atom is electrically neutral. A charged atom, called an *ion,* can have a positive or negative charge. Free electrons also are called ions. An ion is formed when ionizing radiation interacts with an orbiting electron and causes it to be ejected from its orbit, a process called *ionization.* This leaves a positively charged atom (or molecule) and a free electron.

D. RADIATION

Radiation as used here means alpha particles, beta particles, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions. Radiation with enough energy to cause ionization is referred to as *ionizing radiation.* Radiation that lacks the energy to cause ionization is referred to as *non-ionizing radiation.* Examples of non-ionizing radiation include radio waves, microwaves, and visible light.

For radiation-protection purposes, ionization is important because it affects chemical and biological processes and allows the detection of radiation.

For most radiation-protection situations, ionizing radiation takes the form of alpha, beta, and neutron particles, and gamma and X-ray photons.

X-rays and gamma rays are a form of electromagnetic radiation. X-rays differ from gamma rays in their point of origin. Gamma rays originate from within the atomic nucleus, whereas X-rays originate from the electrons outside the nucleus and from free electrons decelerating in the vicinity of atoms (i.e., bremsstrahlung). Chapter 2 discusses how X-rays are produced.

E. UNITS

- Roentgen (R), a measure of radiation *exposure*, is defined by ionization in air.
- Rad, a measure of the energy absorbed per unit mass. It is defined for any absorbing material.
- Rem, a unit of dose equivalent, which is the energy absorbed per unit mass times the applicable quality factor and other modifying factors.

For X-rays, it may be assumed that 1 R = 1 rad = 1 rem = 1000 mrem.

F. BACKGROUND RADIATION

Background radiation, to which everyone is exposed, comes from both natural and manmade sources. Natural background radiation can be categorized as cosmic and terrestrial. Radon is the major contributor to terrestrial background. The most common sources of manmade background radiation are medical procedures and consumer products.

The average background dose to the general population from both natural and manmade sources is about 350 mrem per year to the whole body. Naturally occurring sources contribute an average of 200 mrem per year from radon daughters, about 40 mrem per year from internal emitters such as potassium-40, about 30 mrem per year from cosmic and cosmogenic sources, and about 30 mrem per year from terrestrial sources such as naturally occurring uranium and thorium. Manmade sources contribute an average of about 50 mrem per year to the whole body from medical procedures such as chest X-rays.

The deep dose equivalent from a chest X-ray is 5 - 10 mrem, a dental X-ray is 50 - 300 mrem, and mammography is 0.5 - 2 rem.

G. DOSE LIMITS

Limits on occupational doses are based on data on the biological effects of ionizing radiation. The International Commission on Radiological Protection and the National Council on Radiation Protection and Measurements publish guidance for setting radiation protection standards. The Nuclear Regulatory Commission, Environmental Protection Agency, and Texas Department of State Health Services have set regulatory requirements related to radiation protection. These limits are set to minimize the likelihood of biological effects.

The following table lists the dose limits as set by the Texas Department of State Health Services – Radiation branch. Refer to: 25TAC§289.202(f), (m), (n)

Dose Limits	
whole body Total Effective Dose Equivalent	5 rem/year
extremity	50 rem/year
skin	50 rem/year
internal organ committed dose equivalent	50 rem/year
lens of the eye	15 rem/year
embryo/fetus	0.5 rem/term of pregnancy (for the embryo/fetus of workers who declare pregnancy)
minors and public	0.1 rem/year

H. CAUSES OF ACCIDENTAL EXPOSURES

Although most X-ray workers do not receive radiation doses near the regulatory limit, it is important to recognize that X-ray device-related accidents have occurred when proper procedures have not been followed. Failure to follow proper procedures has been the result of:

- Rushing to complete a job
- Boredom
- Fatigue
- Illness
- Personal problems
- Lack of communication
- Complacency

Every year there are numerous X-ray incidents nationwide. Of these, about one third result in injury to a person.

I. REDUCING EXTERNAL DOSE

Four basic ways to reduce external doses are to:

- Minimize time
- Maximize distance
- Use shielding
- Reduce quantity

Minimize time near a source of radiation by planning ahead. Increase distance by moving away from the source of radiation whenever possible. The dose from X-ray sources is inversely proportional to the square of the distance. This is called the inverse square law, that is, when the distance is doubled, the dose is reduced to one-fourth of the original value. Proper facility design uses the amount and type of shielding appropriate for the radiation hazard. Lead, concrete, and steel are effective in shielding against X-rays. Reduce quantity, perform the procedure or experiment with lower voltage and current settings if possible. By reducing the voltage the maximum X-ray energy is reduced, and by reducing the current the total number of X-rays produced is smaller. In either case the radiation dose will be less.

CHAPTER 2 - PRODUCTION OF X-RAYS

A. OBJECTIVES

i. Module Objective.

Upon completion of this unit, the participants should understand what X-rays are and how they are produced so that the participants will be able to work around them safely.

ii. Objectives.

Following self-study and/or classroom review, the participants will be able to:

1. Define the types of electromagnetic radiation.
2. Describe the difference between X-rays and gamma rays.
3. Identify how X-rays are produced.
4. Define bremsstrahlung and characteristic X-rays.
5. Describe how X-ray tube voltage and current affect photon energy and power.
6. Explain how X-rays interact with matter.
7. Identify how energy relates to radiation dose.
8. Discuss the effects of voltage, current, and filtration on X-rays.

B. ELECTROMAGNETIC RADIATION

1. Types of Electromagnetic Radiation.

X-rays are a type of electromagnetic radiation. Other types of electromagnetic radiation are radio waves, microwaves, infrared, visible light, ultraviolet, and gamma rays. The types of radiation are distinguished by the amount of energy carried by the individual photons.

All electromagnetic radiation consists of photons, which are individual packets of energy. For example, a household light bulb emits about 10^{21} photons of light (non-ionizing radiation) per second.

The energy carried by individual photons, which is measured in electron volts (eV), is related to the frequency of the radiation. Different types of electromagnetic radiation and their typical photon energies are listed in the following table.

Electromagnetic Radiation		
Type	**Typical Photon Energy**	**Typical Wavelengths**
radio wave	1 µeV	1 m
microwave	1 meV	1 mm (10^{-3}m)
infrared	1 eV	1 um (10^{-6}m)
red light	2 eV	6000 Angstrom (10^{-10}m)
violet light	3 eV	4000 Angstrom
ultraviolet	4 eV	3000 Angstrom
X-ray	100 keV	0.1 Angstrom
gamma ray	1 MeV	0.01 Angstrom

2. X-Rays and Gamma Rays.

   X-rays and gamma rays both ionize atoms. The energy required for ionization varies with material (e.g., 34 eV in air, 25 eV in tissue) but is generally in the range of several eV. A 100 keV X-ray can potentially create thousands of ions. As discussed in Chapter 1, the distinction between X-rays and gamma rays is their origin, or method of production. Gamma rays originate from within the nucleus; X-rays originate from atomic electrons and from free electrons decelerating in the vicinity of atoms (i.e., bremsstrahlung).

   In addition, gamma photons often have more energy than X-ray photons. For example, diagnostic X-rays are about 40 keV, whereas gammas from cobalt-60 are over 1 MeV. However, there are many exceptions. For example, gammas from technicium-99m are 140 keV, and the energy of X-rays from a high-energy radiographic machine may be as high as 10 MeV.

C. X-RAY PRODUCTION

Radiation-producing devices produce X-rays by accelerating electrons through an electrical voltage potential and stopping them in a target. Many devices that use a high voltage and a source of electrons produce X-rays as an unwanted byproduct of device operation. These are called *incidental* X-rays.

Most X-ray devices emit electrons from a cathode, accelerate them with a voltage, and allow them to hit an anode, which emits X-ray photons.

1. Bremsstrahlung.

   When electrons hit the anode, they decelerate or brake emitting *bremsstrahlung* (meaning *braking radiation* in German). Bremsstrahlung is produced most effectively when small charged particles interact with large atoms such as when electrons hit a tungsten anode. However, bremsstrahlung can be produced with any charged particles and any target. For example, at research laboratories, bremsstrahlung has been produced by accelerating protons and allowing them to hit hydrogen.

2. Characteristic X-Rays.

   When electrons change from one atomic orbit to another, *characteristic X-rays* are produced. The individual photon energies are characteristic of the type of atom and can be used to identify very small quantities of a particular element. For this reason, they are important in analytical X-ray applications at research laboratories.

D. EFFECT OF VOLTAGE AND CURRENT ON PHOTON ENERGY AND POWER

It is important to distinguish between the energy of individual photons in an X-ray beam and the total energy of all the photons in the beam. It is also important to distinguish between average power and peak power in a pulsed X-ray device.

Typically, the individual photon energy is given in electron volts (eV), whereas the power of a beam is given in watts (W). An individual 100 keV photon has more energy than an individual 10 keV photon. However, an X-ray beam consists of a spectrum (a distribution) of photon energies and the rate at which energy is delivered by a beam is determined by the number of photons of each energy. If there are many more low energy photons, it is possible for the low energy component to deliver more energy.

The photon energy distribution may be varied by changing the voltage. The number of photons emitted may be varied by changing the current.

1. Voltage.

   The power supplies for many X-ray devices do not produce a constant potential (D.C.) high voltage but instead energize the X-ray tube with a time varying or pulsating high voltage. In addition, since the bremsstrahlung X-rays produced are a spectrum of energies up to a maximum equal to the electron accelerating maximum voltage, the accelerating voltage of the X-ray device is often described in terms of the peak kilovoltage or kVp.

   A voltage of 50 kVp will produce a spectrum of X-ray energies with the theoretical maximum being 50 keV. The spectrum of energies is continuous from the maximum to zero. However, X-ray beams are typically filtered to minimize the low-energy component. Low-energy X-rays are not useful in radiography, but can deliver a significant dose.

Many X-ray devices have meters to measure voltage. Whenever the voltage is on, a device can produce some X-rays, even if the current is too low to read.

2. Current.

The total number of photons produced by an X-ray device depends on the current, which is measured in amperes, or amps (A). The current is controlled by increasing or decreasing the number of electrons emitted from the cathode. The higher the electron current, the more X-ray photons are emitted from the anode. Many X-ray devices have meters to measure current. However, as mentioned above, X-rays can be produced by voltage even if the current is too low to read on the meter. This is sometimes called dark current. This situation can cause unnecessary exposure.

E. INTERACTION WITH MATTER

1. Scattering.

When X-rays pass through any material, some will be transmitted, some will be absorbed, and some will scatter. The proportions depend on the photon energy, the type of material and its thickness.

X-rays can scatter off a target to the surrounding area, off a wall and into an adjacent room, and over and around shielding. A common mistake is to install thick shielding walls around an X-ray source but ignore the roof; X-rays can scatter off air molecules over shielding walls to create a radiation field known as *skyshine*. The emanation of X-rays through and around penetrations in shielding walls is called *radiation streaming*.

2. Implications of Power and X-Ray Production.

When high-speed electrons strike the anode target, most of their energy is converted to heat in the target, but a portion is radiated away as X-rays. The electrical power of an electrical circuit is given by:

$$P = V \times I$$

P is the power in watts or joules/second, V is the potential difference in volts, and I is the current in amps.

The power developed in the anode of an X-ray tube can be calculated using this relationship. Consider a 150 kilovolt (kVp) machine, with a current of 50 milliamps (mA).

$$P = [150{,}000\ (V)]\ [0.050\ (I)] = 7500\ W.$$

This is about the same heat load as would be found in the heating element of an electric stove. This power is delivered over a very short period of time, typically less than 1 second. More powerful X-ray machines use higher voltages and currents and may develop power as high as 50,000 W or more. Cooling the anode is a problem that must be addressed in the design of X-ray machines. Tungsten is used because of its high melting temperature, and copper is used because of its excellent thermal conductivity. These elements may be used together, with a tungsten anode being embedded in a large piece of copper.

The percentage of the power transformed to X-rays can be estimated by the following relationship:
Fraction of incident electron energy transformed into X-ray energy equals:

$$(7 \times 10^{-4}) \times Z \times E$$

Where Z is the atomic number of the element (74 for tungsten) and E is the maximum energy of the incoming electrons in MeV.

In this case, the fraction would be:

$$(7 \times 10^{-4}) \times 74 \times 0.150 = 0.008$$

In the above example P is 7500 W. So the electron energy incident upon the anode is:

$$7500\ W = 7500\ J/s$$

Then the energy transformed into X-rays would be 0.008 [7500] = 60 J/s.

$$1\ J = 10^{7}\ \text{ergs, and } 100\ \text{ergs/g} = 1\ \text{rad}.$$

So this X-ray energy represents:

6.0×10^8 ergs/sec.

If all this X-ray energy were deposited in 1 g of tissue, the dose would be:

6.0×10^8 ergs/sec [1 rad/100ergs/g] =

6.0×10^6 rad/sec.

However, in practical applications X-ray beams are filtered to remove softer X-rays not useful in radiology, the X-ray pulse is much less than 1 second, and the useful beam region is several cm away from the anode target. These design features lower the dose rates of the useful X-ray beam significantly. The dose rate in a typical X-ray beam is estimated in Module 103 section E iii.

3. Filtration.

Low- and high-energy photons are sometimes referred to as *soft* and *hard* X-rays, respectively. Because hard X-rays are more penetrating, they are more desirable for radiography (producing a photograph of the interior of the body or a piece of apparatus). Soft X-rays are less useful for radiography because they are largely absorbed near the surface of the body being X-rayed. However, there are medical applications where soft X-rays are useful.

A filter, such as a few millimeters of aluminum, or copper may be used to *harden* the beam by absorbing most of the low-energy photons. The remaining photons are more penetrating and are more useful for radiography.

In X-ray analytical work (X-ray diffraction and fluorescence), filters with energy selective absorption edges are not used to *harden* the beam, but to obtain a more monochromatic beam (a beam with predominantly one energy). By choosing the right element, it is possible to absorb a band of high-energy photons preferentially over an adjacent band of low energy photons.

CHAPTER 3 - BIOLOGICAL EFFECTS

A. OBJECTIVES

i. Module Objective.

Upon completion of this unit, the participants should understand the biological effects of X-rays and the importance of protective measures for working with or around X-rays.

ii. Objectives.

Following self-study and/or classroom review, the participants will be able to:

1. Outline the early history of X-rays and the consequences of working with or around X-rays without protective measures.
2. Identify factors that determine the biological effects of X-ray exposure.
3. State the differences between thermal and X-ray burns.
4. Identify the signs and symptoms of an acute dose from X-rays.
5. Explain the effects of chronic exposure to X-rays.
6. Identify the difference between somatic and heritable effects.

B. EARLY HISTORY OF X-RAYS

1. Discovery of X-Rays.

X-rays were discovered in 1895 by German scientist Wilhelm Roentgen. On November 8, 1895, Roentgen was investigating high-voltage electricity and noticed that a nearby phosphor glowed in the dark whenever he switched on the apparatus. He quickly demonstrated that these unknown "x" rays, as he called them, traveled in straight lines, penetrated some materials, and were stopped by denser materials. He continued experiments with these “x” rays and eventually produced an X-ray picture of his wife's hand showing the bones and her wedding ring. On January 1, 1896, Roentgen mailed copies of this picture along with his report to fellow scientists.

By early February 1896, the first diagnostic X-ray in the United States was taken, followed quickly by the first X-ray picture of a fetus in utero. By March of that year, the first dental X-rays were taken.

2. Discovery of Harmful Effects.

   Because virtually no protective measures were used in those early days, it was not long after the discovery of X-rays before people began to learn about their harmful effects. X-ray workers were exposed to very large doses of radiation, and skin damage from that exposure was observed and documented early in 1896. In March of that year, Thomas Edison reported eye injuries from working with X-rays. By June, experimenters were being cautioned not to get too close to X-ray tubes. By the end of that year, reports were being circulated about cases of hair loss, reddened skin, skin sloughing off, and lesions. Some X-ray workers lost fingers, and some eventually contracted cancer. By the early 1900s, the potential carcinogenic effect of X-ray exposure in humans had been reported.

   Since that time, more than a billion dollars has been spent in this country alone on research investigating the biological effects of ionizing radiation. National and international agencies have formed to aid in the standardization of the uses of X-rays to ensure safer practices.

C. BIOLOGICAL EFFECTS OF IONIZATION

X-rays can penetrate into the human body and ionize atoms. This process creates radicals that can break or modify chemical bonds within critical biological molecules. This can cause cell injury, cell death, and may be the cause of radiation-induced cancer. The biological effect of radiation depends on several factors (discussed below) including the dose and dose rate.

In some cases, altered cells are able to repair the damage. However, in other cases, the effects are passed to daughter cells through cell division and after several divisions can result in a group of cells with altered characteristics. These cells may result in tumor or cancer development. If enough cells in a body organ are injured or altered, the functioning of the organ can be impaired.

D. FACTORS THAT DETERMINE BIOLOGICAL EFFECTS

Several factors contribute to the biological effects of X-ray exposure, including:

- Dose rate
- Total dose received
- Energy of the radiation
- Area of the body exposed
- Individual sensitivity
- Cell sensitivity

1. Dose Rate

The rate of dose delivery is commonly categorized as *acute* or *chronic*. An *acute* dose is received in a short period (seconds to days); a *chronic* dose is received over a longer period (months to years).

For the same total dose, an acute dose is more damaging than a chronic dose. It is believed that this effect is due to the ability of cells to repair damage over time. With an acute dose, a cell may receive many “hits” without sufficient time to repair damage.

2. Total Dose Received

The higher the total amount of radiation received, the greater the biological effects. The effects of a whole body dose of less than 25 rem are generally not clinically observable. For doses of 25-100 rem there are generally no symptoms, but a few persons may exhibit mild prodromal symptoms, such as nausea and anorexia. Bone-marrow damage may be noted, and a decrease in red and white blood-cell counts and platelet count should be discernable. 100-300 rem may result in mild to severe nausea, malaise, anorexia, and infection. Hematologic damage will be more severe. Recovery is probable, though not assured.

Although effects of lower doses have not been observed directly, it is conservatively assumed that the higher the total dose, the greater the risk of contracting fatal cancer without consideration of a threshold for effects. This conservative assumption is sometimes called the "linear no threshold" relationship of health effects to dose.

3. Energy of the Radiation

   The energy of X-rays can vary from less than 1 keV up to more than 10 MeV. The higher the energy of the X-ray, the more penetrating it will be into body tissue.

   Lower energy X-rays are largely absorbed in the skin. They can cause a significant skin dose but may contribute little dose to the whole body (depending on energy).

4. Area of the Body Exposed

   Just as a burn to a large portion of the body is more damaging than a burn confined to a smaller area, so also is a radiation dose to the whole body more damaging than a dose to only a small area. In addition, the larger the area, the more difficult it is for the body to repair the damage.

5. Individual Sensitivity

   Some individuals are more sensitive to radiation than others. Age, gender, and overall health can have an effect on how the body responds to radiation exposure.

6. Cell Sensitivity

   Some cells are more sensitive to radiation than others. Cells that are more sensitive to radiation are *radiosensitive;* cells that are less sensitive to radiation are *radioresistant*.

   The law of Bergonie and Tribondeau states: The radiosensitivity of a tissue is directly proportional to its reproductive capacity and inversely proportional to its degree of differentiation.

It is generally accepted that cells tend to be radiosensitive if they are:

1) Cells that have a high division rate
2) Cells that have a high metabolic rate
3) Cells that are of a non-specialized type
4) Cells that are well nourished

The following are radiosensitive tissues:

1) Germinal
2) Hematopoietic
3) Epithelium of the skin
4) Epithelium of the gastrointestinal tract

The following are radioresistant tissues:

1) Bone
2) Liver
3) Kidney
4) Cartilage
5) Muscle
6) Nervous system tissue

E. SOMATIC EFFECTS

Somatic effects are biological effects that occur in the individual exposed to radiation. Somatic effects may result from acute or chronic doses of radiation.

1. Early Acute Somatic Effects.

The most common injury associated with the operation of X-ray analysis equipment occurs when a part of the body, usually a hand, is exposed to the primary X-ray beam. Both X-ray diffraction and fluorescence analysis equipment generate high-intensity, low-energy X-rays that can cause severe and permanent injury if any part of the body is exposed to the primary beam.

The most common injury associated with the operation of industrial X-ray equipment occurs when an operator is exposed to the primary X-ray beam for as little as a few seconds.

These types of injuries are sometimes referred to as *radiation burns*.

2. Difference Between X-Ray Damage and Thermal Burns

   Most nerve endings are near the surface of the skin, so they give immediate warning of heat or a surface thermal burn such as the participants might receive from touching a high-temperature object. In contrast, the body can not immediately feel exposure to X-rays. X-ray damage has historically been referred to as a radiation "burn," perhaps because the reaction of the skin after the radiation exposure may appear similar to a thermal burn. In fact, X-ray damage to the tissue is very different from a thermal burn and there is no sensation or feeling as the damage is occurring.

   In radiation burns, the radiation does not harm the outer, mature, nondividing skin layers. Rather, most of the X-rays penetrate to the deeper, basal skin layer, damaging or killing the rapidly dividing germinal cells that are otherwise destined to replace the outer layers that slough off. Following this damage, as the outer cells are naturally sloughed off, they are not replaced. Lack of a fully viable basal layer of cells means that X-ray burns are slow to heal, and in some cases may never heal. Frequently, such burns require skin grafts. In some cases, severe X-ray burns have resulted in gangrene and amputation.

   An important variable is the energy of the radiation because this determines the depth of penetration in a given material. Heat radiation is infrared, typically 1 eV; sunburn is caused by ultraviolet rays, typically 4 eV; and X-rays are typically 10 - 100 keV, which are capable of penetrating to the depth of the basal layer of the skin.

3. Early Signs and Symptoms of Accidental Exposure to X-Rays.

   Note: the doses discussed in this section are localized shallow skin doses and/or localized doses, but not whole body doses. Whole body deep doses of this magnitude would likely be fatal. Accidental exposures from RPDs are generally localized to a small part of the body.

   ~600 rad. An acute dose of about 600 rad to a part of the body causes a radiation burn equivalent to a first-degree thermal burn or mild sunburn. Typically there is no immediate pain that would cause the participants to pull away, but a sensation of warmth or itching occurs within a few hours after exposure. An initial reddening or inflammation of the affected area usually appears several hours after exposure and fades after a few more hours or days. The reddening may reappear as late as two to three weeks after the exposure. A dry scaling or peeling of the irradiated portion of the skin is likely to follow.

If the participants have been working with or around an X-ray device and the participants notice an unexplained reddening of the skin, notify the supervisor and the Occupational Medicine Group. Aside from avoiding further injury and guarding against infection, further medical treatment will probably not be required and recovery should be fairly complete.

An acute dose of 600 rad delivered to the lens of the eye causes a cataract to begin to form.

~1,000 rad. An acute dose of about 1,000 rad to a part of the body causes serious tissue damage similar to a second-degree thermal burn. First reddening and inflammation occur, followed by swelling and tenderness. Blisters will form within one to three weeks and will break open, leaving raw painful wounds that can become infected. Hands exposed to such a dose become stiff, and finger motion is often painful. If the participants develop symptoms such as these, seek immediate medical attention to avoid infection and relieve pain.

~2,000 rad. An acute dose of about 2,000 rad to a part of the body causes severe tissue damage similar to a scalding or chemical burn. Intense pain and swelling occur within hours. For this type of radiation burn, seek immediate medical treatment to reduce pain. The injury may not heal without surgical removal of exposed tissue and skin grafting to cover the wound. Damage to blood vessels also occurs.

~3,000 rad. An acute dose of 3,000 rad to a part of the body completely destroys tissue and surgical removal is necessary.

It does not take long to get a significant dose from an X-ray unit.

4. Latent Effects from Radiation Exposure.

   The probability of a latent effect appearing several years after radiation exposure depends on the amount of the dose. The higher the dose, the greater the risk of developing a health effect. When an individual receives a large accidental exposure and the prompt effects of that exposure have been dealt with, there still remains a concern about latent effects years after the exposure. Although there is no unique disease associated with exposure to radiation, there is a possibility of developing fatal cancer. The higher the accumulated dose, the greater is the risk of health effect, based on the linear-no threshold model.

5. Risk of Developing Cancer from Low Doses.

   It is not possible to absolutely quantify the risk of cancer from low doses of radiation because the health effects cannot be distinguished from the relatively large natural cancer rate (approximately 20 percent of Americans die from cancer). The risk of health effects from low doses must be inferred from effects observed from high acute doses. The risk estimates for high doses were developed through studies of Japanese atomic bomb survivors, uranium miners, radium watch-dial painters, and radiotherapy patients. These risk factors are applied to low doses with a reduction factor for chronic exposures.

   However, below 10 rem, health effects are too small to measure. The dose limits listed in Chapter 1 have been established so that the risk to workers is on a par with the risks to workers in safe industries, assuming a linear relationship between dose and health effects. However, these are maximum values and the ALARA principle stresses maintaining doses well below these values.

6. Effects of Prenatal Exposure (Teratogenic Effects).

   The embryo/fetus is especially sensitive to radiation. The embryo is sensitive to radiation because of the relatively high replication activity of the cells and the large number of nonspecialized cells.

   Workers who become pregnant are encouraged to declare their pregnancy in writing to their supervisors. The dose limit for the embryo/fetus of a declared pregnant worker is 500 mrem during the term of the pregnancy; 25TAC§289.202(m)(2) states "The licensee shall make efforts to avoid substantial variation above a uniform monthly exposure rate to a declared pregnant woman so as to satisfy the limit in 25TAC§289.202(m)(1)." [i.e., 500 mrem for term of pregnancy]

F. HERITABLE EFFECTS

Heritable effects are biological effects that are inherited by children from their parents at conception. Irradiation of the reproductive organs can damage cells that contain heritable information passed on to offspring.

Radiation-induced hereditary effects have been observed in large-scale experiments with fruit flies and mice irradiated with large doses of radiation. Such health effects have not been observed in humans. Based on the animal data, however, the conservative assumption is made that radiation-induced hereditary effects could occur in humans.

Radiation-induced heritable effects do not result in genetic diseases that are uniquely different from those that occur naturally. Extensive observations of the children of Japanese atomic bomb survivors have not revealed any statistically significant hereditary health effects.

Note: *Congenital (teratogenic) effects are not heritable effects. Congenital effects are not inherited; they are caused by the action of agents such as drugs, alcohol, radiation, or infection to an unborn child in utero. Congenital or teratogenic effects did occur in children who were irradiated in utero by the atomic bombs at Hiroshima or Nagasaki.*

CHAPTER 4 - RADIATION DETECTION

A. OBJECTIVES

i. Module Objective.

Upon completion of this unit, the participants should understand which radiation-monitoring instruments that are appropriate for detecting X-rays.

ii. Objectives.

Following self-study and/or classroom review, the participants will be able to:

1. Identify the instruments used for X-ray detection.

B. RADIATION SURVEYS

Radiation protection surveys should be conducted on all new or newly installed X-ray devices by the Risk Management & Safety Office and repeated at a frequency as identified in the Radiation Safety Manual (Section III.A.5).

C. X-RAY DETECTION INSTRUMENTS

External exposure controls used to minimize the dose equivalent to workers are based on the data taken with portable radiation-monitoring instruments during a radiation survey. An understanding of these instruments is important to ensure that the data obtained are accurate and appropriate for the source of radiation.

Many factors can affect how well the survey measurement reflects the actual conditions, including:

- Selection of the appropriate instrument based on type and energy of radiation and on radiation intensity.
- Correct operation of the instrument based on the instrument operating characteristics and limitations.
- Calibration of the instrument to a known radiation field similar in type, energy, and intensity to the radiation field to be measured.

Instruments Used for X-Ray Detection

It is important to distinguish between detection and measurement of X-rays. Equipment users often use a detector to detect the presence of X-rays, for example, to verify that the device is off before entry into the area. The measurement of X-rays is normally the job of a qualified Radiological Control Technician.

Measurement of radiation dose rates and surveys of record require an instrument that reads roentgen or rem (R/hour, mR/hour, rem/hour, mrem/hour) rather than counts per minute (cpm) or disintegrations per minute (dpm). Ion chambers measure energy deposited and are good instruments for measuring X-ray radiation dose levels.

Instruments such as Geiger-Mueller (GM) counters are effective for detection of radiation because of their good sensitivity. However, because both low-energy and high-energy photons discharge the counter, GM counters do not quantify a dose well. A thin-window GM counter is the instrument of choice for the detection of X-rays. However, this is not the instrument of choice for measurement of X-ray dose.

CHAPTER 5 - PROTECTIVE MEASURES

A. OBJECTIVES

i. Module Objective.

Upon completion of this unit, the participants should understand protective measures that restrict or control access to X-ray areas and devices or warn of X-ray hazards, and should be able to use work documents that provide specific procedures to ensure safe operation of X-ray devices.

ii. Objectives.

Following self-study and/or classroom review, the participants will be able to:

1. Identify and state specific administrative and engineered controls.

2. Identify and state specific radiological postings.

3. Define “interlocks”, as applicable.

4. Explain specific shielding practices.

5. Identify typical RPD warning devices.

B. RADIOLOGICAL CONTROLS

To control exposure to radiation, as well as maintain exposure ALARA, access to radiological areas is restricted by a combination of administrative and engineering controls.

Examples of administrative controls include:

- Postings
- Warning signals and labels
- Work control documents such as SOPs

Examples of engineered controls include:

- Interlocks
- Shielding

C. RADIOLOGICAL POSTINGS

1. Purpose of Posting

The primary reason for radiological posting is to inform workers of the radiological conditions in an area.

2. General Posting Requirements

1. Signs contain the standard radiation symbol colored magenta or black on a yellow background.

2. Signs shall be clearly and conspicuously posted to alert personnel to the presence of radiation. Signs may also include radiological protection instructions.

3. If more than one radiological condition exists in the same area, each condition should be identified.

4. Rope, tape, chain, or similar barrier material used to designate radiological areas should be yellow and magenta.

5. Physical barriers should be placed so that they are clearly visible from all accessible directions and at various elevations.

6. Posting of doors should be such that the postings remain visible when doors are open or closed.

7. Radiological postings that indicate an intermittent radiological condition should include a statement specifying when the condition exists, such as

"CAUTION, RADIATION AREA WHEN RED LIGHT IS ON."

For a Radiation Area, wording on the posting shall include the words:

"CAUTION, RADIATION AREA."

D. INTERLOCKS

Fail-safe interlocks should be provided on doors and access panels of X-ray devices so that X-ray production is not possible when they are open. A fail-safe interlock is designed so that any failure that can reasonably be anticipated will result in a condition in which personnel are safe from excessive radiation exposure.

Guidance from the ANSI standards is that interlocks should be tested by the operating group at least every six months. The interlock test procedure may be locally specified, but typically is as follows:

- Energize the X-ray tube.
- Open each door or access panel one at a time.
- Observe the X-ray warning light or current meter at the control panel.
- Record the results in a log.

E. SHIELDING

1. Analytical Systems

For analytical X-ray machines, such as X-ray fluorescence and diffraction systems, the manufacturer provides shielding in accordance with ANSI N43.2. However, prudent practice requires that any device or source that involves radiation should be surveyed to determine the adequacy of the shielding.

Enclosed beam systems have sufficient shielding so that the dose rate at 5 cm from its outer surface does not exceed 0.25 mrem per hour under normal operating conditions. The dose rate may be difficult to evaluate. According to ANSI N43.2, this requirement is met if the shielding is at least equal to the thickness of lead specified in the following table for the maximum rated anode current and potential.

MINIMUM SHIELDING TO KEEP THE DOSE RATE BELOW 0.25 MREM / HOUR			
ANODE CURRENT	MILLIMETERS OF LEAD		
(MA)	50 KVP	70 KVP	100 KVP
20	1.5	5.6	7.7
40	1.6	5.8	7.9
80	1.6	5.9	--
160	1.7	--	--

2. Industrial Systems

Some industrial X-ray systems, such as the cabinet X-ray systems used for airport security, are completely enclosed in an interlocked and shielded cabinet. Larger systems such as medical X-ray units are enclosed in a shielded room to which access is restricted. Shielding for X-ray rooms is conservatively designed to handle the expected workload conditions. Radiological control technicians (RCTs) periodically verify that the shielding integrity has not deteriorated.

F. WARNING DEVICES

Operators should be aware of the status of the X-ray tube. Indicators that warn of X-ray production typically include:

- A current meter on the X-ray control panel
- A warning light labeled X-RAYS ON near or on the control panel
- Warning light labeled X-RAYS ON near any X-ray room door

These warning lights or indicators are activated automatically when power is available for X-ray production.

For X-ray systems with an open beam in a shielded room, evacuation warning signals and signs must be activated at least 20 seconds before X-ray production can be started. Any person who is inside the room when warning signals come on should immediately leave the room and activate the panic or scram switch on the way out. This is an emergency system designed to shut down the X-ray system immediately.

G. WORK DOCUMENTS

An X-ray device has a procedure such as an SOP to promote safe and efficient operation. SOPs typically include the following:

1. Description/specification of the X-ray device and the purpose for which it is used.
2. Normal X-ray parameters (peak power, current, exposure time, X-ray source-to-film distance, etc.).
3. Procedures for proper sample preparation, alignment procedures, or handling of object to be radiographed.
4. Description of all safety hazards (electrical, mechanical, explosive, as well as radiation hazards) associated with the operation of the X-ray device.
5. Description of the safety features such as interlocks and warning signals and any other safety precautions.
6. Procedures for performing interlock tests and the recommended frequency of such tests.
7. Required operator training and dosimetry.
8. Posting of signs and labels.
9. X-ray device safety checklist (items to be checked periodically or each day before use).
10. Actions to take in the event of an abnormal occurrence or emergency.
11. Requirements for the use of a radiation-monitoring instrument upon entry into the Radiation Area to verify that the X-ray beam is off are specified in ANSI N43.3 for some industrial X-ray devices.

Operating groups are responsible for ensuring that the operator becomes familiar with and uses the SOP. The operator is responsible for following the SOP.

CHAPTER 6 - X-RAY GENERATING DEVICES

A. OBJECTIVES

i. Module Objective.

Upon completion of this unit, the participants should understand the categories of X-ray producing devices and the hazards associated with each.

ii. Objectives.

Following self-study and/or review, the participants will be able to:

1. Contrast incidental and intentional X-ray devices.

2. Contrast analytical and industrial X-ray devices.

3. Identify open and enclosed beam installations.

4. Describe the safety features essential for operation of industrial and analytical systems.

B. INCIDENTAL AND INTENTIONAL DEVICES

X-ray systems are divided into two broad categories: intentional and incidental.

An *incidental* X-ray device produces X-rays that are not wanted or used as a part of the designed purpose of the machine. Shielding of an incidental X-ray device should preclude significant exposure. Examples of incidental systems are computer monitors, televisions, electron microscopes, high-voltage electron guns, electron beam welding machines, electrostatic separators, and Jennings switches.

An *intentional* X-ray device is designed to generate an X-ray beam for a particular use. Examples include X-ray diffraction and fluorescence analysis systems, flash X-ray systems, medical X-ray machines, and industrial cabinet and noncabinet X-ray equipment. Intentional X-ray devices are further divided into two subcategories: analytical and industrial.

ANSI has issued two standards that provide radiation safety guidelines for X-ray systems. ANSI N43.2 applies to non-medical X-ray systems and ANSI N43.3 applies to X-ray diffraction and fluorescence systems.

C. INCIDENTAL X-RAY DEVICES

1. Exempt Shielded Systems.
   Exempt shielded systems are defined in the ANSI Standard N43.3. Electron microscopes and other systems that are exempt shielded are inherently safe, and require review only on purchase or modification. The exposure rate during any phase of operation of these devices at the maximum-rated continuous beam current for the maximum-rated accelerating potential should not exceed 0.5 mrem/hour at 2 inches (5 cm) from any accessible external surface.

2. Other Devices.
   At a research laboratory, many devices produce incidental X-rays. Any device that combines high voltage and a vacuum could, in principle, produce X-rays. For example, a television or computer monitor generates incidental X-rays, but in modern designs the intensity is small, much less than 0.5 mrem/hour.
   Occasionally, this hazard is recognized only after the device has operated for some time. If the participants suspect an X-ray hazard, contact THE Risk Management & Safety Office to survey the device.

D. INTENTIONAL ANALYTICAL X-RAY DEVICES

1 Analytical X-Ray Devices.

Analytical X-ray devices use X-rays for diffraction or fluorescence experiments. These research tools are normally used in materials science. ANSI N43.2 defines two types of analytical X-ray systems: enclosed beam and open beam.

The following safety features are common to both systems:

a. A fail-safe light or indicator is installed in a conspicuous location near the X-ray tube housing. These indicators are energized automatically and only when the tube current flows or high voltage is applied to the X-ray tube.

b. Accessories to the equipment have a beam stop or other barrier.

c. Shielding is provided.

2. Enclosed-Beam System.

In an enclosed-beam system, all possible X-ray paths (primary and diffracted) are completely enclosed so that no part of a human body can be exposed to the beam during normal operation. Because it is safer, the enclosed-beam system should be selected over the open-beam system whenever possible.

The following safety features are specified by ANSI N43.2 for an enclosed-beam X-ray system:

a. The sample chamber door or other enclosure should have a fail-safe interlock on 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.

b. X-ray tube, sample, detector, and analyzing crystal (if used) must be enclosed in a chamber or coupled chambers that cannot be entered by any part of the body during normal operation.

c. Radiation leakage measured at 2 inches (5 cm) from any outer surface must not exceed 0.25 mrem/hour during normal operation.

3. Open-Beam System.

According to ANSI N43.2, a device that does not meet the enclosed-beam standards is classified as an open-beam system. In an open-beam system, one or more X-ray beams are not enclosed, making exposure of human body parts possible during normal operation. The open-beam system is acceptable for use only if an enclosed beam is impractical because of any of the following reasons:

a. A need for frequent changes of attachments and configurations.
b. A need for making adjustments with the X-ray beam energized.
c. Motion of specimen and detector over wide angular limits.
d. The examination of large or bulky samples.

The following safety features are essential in an open-beam X-ray system:

a. Each port of the X-ray tube housing must have a beam shutter.
b. All shutters must have a conspicuous SHUTTER OPEN indicator of fail-safe design.
c. Shutters at unused ports should be mechanically or electrically secured to prevent casual opening.
d. Special rules apply when the accessory setup is subject to change as is the case with powder diffraction cameras. In these cases, the beam shutter must be interlocked so the port will be open only when the accessory is in place.
e. Exposure rates adjacent to the system must not exceed 2.5 mrem/hour at 5cm from the surface of the housing.
f. A guard or interlock must prevent entry of any part of the body into the primary beam.

E. INTENTIONAL INDUSTRIAL X-RAY DEVICES

1. Industrial X-Ray Devices.

Industrial X-ray devices are used for radiography, for example, to take pictures of the inside of an object as in an X-ray of a pipe weld or to measure the thickness of material. ANSI standard N43.3 defines five classes of industrial X-ray installations: cabinet, exempt shielded, shielded, unattended, and open.

(Add facility-specific examples.)

2. Cabinet X-ray Installation.

A cabinet X-ray installation is similar in principle to the analytical enclosed beam system. The X-ray tube is installed in an enclosure (cabinet) that contains the object being irradiated, provides shielding, and excludes individuals from its interior during X-ray generation. A common example is the X-ray device used to inspect carry-on baggage at airline terminals. Certified cabinet X-ray systems comply with the regulations of 21 CFR 1020.40. Exposure rates adjacent to a cabinet X-ray system shall not exceed 2 mrem/hour.

3. Exempt Shielded Installation.

An exempt shielded facility or installation is similar to a cabinet X-ray installation. It provides a high degree of inherent safety because the protection depends on passive shielding and not on compliance with procedures. This type does not require restrictions in occupancy since passive shielding is sufficient. The low allowable dose equivalent rate of 0.5 mrem in any 1 hour 5 cm from the accessible surface of the enclosure for this class of installation necessitates a high degree of installed shielding surrounding the X-ray device.

4. Shielded Installation.

A shielded installation has less shielding than exempt shielded. This is a cost advantage for fixed installations, particularly for high-energy sources where the reduction in shielding may result in significant savings. However, there is more reliance on protective measures such

as warning lights, posting, and procedures. However, the posting and access control requirements, of 10 CFR 835 apply. Any High Radiation Area must be appropriately controlled and any Radiation Area must be defined and posted.
(Add facility-specific examples.)

5. Unattended Installation.
An unattended installation consists of equipment designed and manufactured for a specific purpose and does not require personnel in attendance for its operation. Steps must be taken to ensure that the dose to personnel is less than 100 mrem/year. However, a short term limit of 2 mrem/hour may be used provided the expected dose to personnel is less than 100 mrem/year.
(Add facility-specific examples.)

6. Open Installation.
An open installation has X-ray paths that are not enclosed. An example would be a portable X-ray machine outdoors in an emergency response situation, with the X-ray tube not enclosed inside a shielded room. This class is acceptable for use only if operational requirements prevent the use of one of the other classes. Its use is limited mainly to mobile and portable equipment where fixed shielding cannot be used. The protection of personnel and the public depends almost entirely on strict adherence to safe operating procedures and posting. High Radiation Areas must either be locked (as in the shielded installation) or be under constant surveillance by the operator. The perimeter of any Radiation Area created by the system must be defined and posted.

According to ANSI N43.3, when the radiation source is being approached following the conclusion of a procedure, the operator shall use a suitable calibrated and operable survey instrument to verify that the source is in its fully shielded condition or that the X-ray tube has been turned off.

F. SUMMARY OF X-RAY DEVICES

The following table summarizes the classes of X-ray devices recognized by ANSI. For the enclosed beam, exempt shielded, and cabinet systems, access is controlled by enclosing the X-rays within a chamber or cabinet. The other systems can have potentially hazardous dose rates outside the system housing, so access must be controlled by a combination of locked doors, posting, warning lights, and procedures.

SUMMARY OF X-RAY DEVICES

X-Ray Device	Category	Maximum Dose Rate - Whole Body	Access
Enclosed beam	Analytical	0.25 mrem/hour	Fully enclosed chamber
Open beam	Analytical	2.5 mrem/hour	Beam guard
Cabinet	Industrial	2.0 mrem/hour	Fully enclosed in a cabinet
Exempt shielded	Industrial	0.5 mrem/hour	Enclosed
Shielded	Industrial	as posted	Locked doors
Unattended	Industrial	2 mrem/hour - maximum 100 mrem/year	Secured access panel
Open installation	Industrial	as posted	Constant surveillance

CHAPTER 7 - RESPONSIBILITIES FOR X-RAY SAFETY

A. OBJECTIVES

i. Module Objective.

Upon completion of this unit, the participants will understand who is responsible for implementing X-ray safety policies and procedures and what their specific responsibilities are.

ii. Objectives.

Following self-study and/or classroom review, the participants will be able to:

1. State the responsibilities of the Risk Management & Safety Office.

2. State the responsibilities of operating groups regarding X-ray safety.

3. State the responsibilities of X-ray device custodians.

4. State the responsibilities of X-ray device operators.

B. RESPONSIBILITIES

The responsibility for maintaining exposures from X-rays ALARA is shared among the personnel assigned to the X-Ray Device Control Office, the operating groups, X-ray device custodians, and X-ray device operators.

1. Risk Management & Safety Office
   a. Establishing requirements and standards.
   b. Offering safety training.

c. Approving purchases, moves, transfers, and alterations of X-ray equipment.

d. Surveying new equipment, verifying that the appropriate safety program requirements have been met, and affixing compliance labels to the devices.

2. Operating Groups.

a.. Complying with all X-ray safety requirements.

b. Registering X-ray machines.

c. Preparing SOPs.

d. Ensuring proper training of operators.

3 X-Ray Device Custodians.

X-ray device custodians are responsible for specific X-ray generating machines. Their duties include:

1. Completing X-Ray-Generating Device Registration forms and submitting them to the RMSO to register new intentional X-ray devices, and new X-ray tube assemblies or source housings.
2. Making arrangements for operator training.
3. Maintaining a list of qualified operators authorized for particular machines.
4. Documenting that operators have read the appropriate SOPs and machine safety features.
5. Posting an authorized operator list near the control panel of each X-ray device.
6. Checking enclosure door safety interlocks every six months to ensure proper functioning and recording results on an interlock test log posted on or near the control panel.
7. Contacting the RMSO before performing any repair, maintenance, and/or non-routine work that could cause the exposure of any portion of the body to the primary beam.

4. X-Ray Device Operators

Authorized X-ray device operators are responsible for knowing and following the operator safety checklist, including:

a. Knowing the SOP for every machine operated.
b. Notifying his/her supervisor of any unsafe or hazardous work situations.
c. Before reaching into the primary beam, verifying that the beam shutter is closed or that machine power is off.
d. Meeting all applicable training requirements before operating RPD.
e. Maintaining exposures ALARA.

REFERENCES

- DOE-HDBK-1109-97, Radiological Safety Training for Radiation Producing (X-Ray) Devices Student's Guide
- 25TAC§289.202, Standards in Protection Against Radiation from Radioactive Material
- 25TAC§289.228, Radiation Safety Requirements for Analytical and Other Industrial Radiation Machines
- 25TAC§289.231, General Provisions and Standards in Protection Against Machine-Produced Radiation

Absorbed dose: The energy absorbed by matter from ionizing radiation per unit mass of irradiated material at the place of interest in that material. The absorbed dose is expressed in units of rad.
(10 CFR 835.2(b)).

Access panel: Any barrier or panel that is designed to be removed or opened for maintenance or service purposes, requires tools to open, and permits access to the interior of the cabinet. *See also* door, port, and aperture.

Access port: *See* port.

Analytical X-ray device. A group of components that use intentionally produced X-rays to evaluate, typically through X-ray diffraction or fluorescence, the phase state or elemental composition of materials. Local components include those that are struck by X-rays such as the X-ray source housings, beam ports and shutter assemblies, collimators, sample holders, cameras, goniometers, detectors, and shielding. Remote components include power supplies, transformers, amplifiers, readout devices, and control panels.

Anode: The positive electrode in an X-ray device that emits X-rays after being struck by energetic electrons from the cathode.

Aperture: In this context, the opening within an X-ray source housing that permits the primary X-ray beam to emerge in the intended direction. Such an aperture is not necessarily an open hole, but rather may be a portion of the metal wall of the X-ray source housing that is significantly thinner than the surrounding X-ray source housing walls.

Attenuation: The reduction of a radiation quantity upon passage of the radiation through matter, resulting from all types of interaction with that matter. The radiation quantity may be, for example, the particle fluency rate.

GLOSSARY (continued)

As low as reasonably achievable (ALARA): Mean the approach to radiation protection to manage and control exposures (both individual and collective) to the work force and to the general public to as low as is reasonable, taking into account social, technical, economic, practical and public policy considerations. ALARA is not a dose limit but a process which has the objective of attaining doses as far below the applicable limits of 10 CFR 835 as is reasonably achievable. (10 CFR 835.2(a))

Bremsstrahlung: The electromagnetic radiation emitted when an electrically charged subatomic particle, such as an electron, loses energy upon being accelerated and deflected by the electric field surrounding an atomic nucleus. In German, the term means *braking radiation.*

Cabinet X-ray system: An industrial X-ray device with the X-ray tube installed in an enclosure (cabinet) that, independent of existing architectural structures except the floor upon which it may be placed, is intended to contain at least that portion of a material being irradiated, provide radiation attenuation, and exclude individuals from its interior during X-ray generation. Included are all X-ray devices designed primarily for the inspection of carry-on baggage at airline, railroad, and bus terminals. *Excluded* from this definition are X-ray devices using a building wall for shielding and those using portable shields on a temporary basis.

Cathode: The negative electrode that emits electrons in an X-ray device.

Collimator: A device used to limit the size, shape, and direction of the primary beam.

Control panel: A device containing the means for regulating and activating X-ray equipment or for preselecting and indicating operating factors.

Controlled Area: Any area to which access is managed to protect individuals from exposure to radiation and/or radioactive material.

GLOSSARY (continued)

Dark current: A current, usually of electrons, that may flow through an acceleration tube or wave guide from sources other than the cathode of the accelerator. This is an abnormal phenomenon, often associated with poor vacuum conditions or contaminated surfaces in the acceleration region.

Door: In this context, any barrier that is designed to be moved or opened for routine operation purposes, does not require tools to open, and permits access to the interior of the cabinet.

Dose equivalent: The product of absorbed dose, a quality factor, and other modifying factors. The unit of dose equivalent is the rem. (10 CFR 835.2 (b))

Electron volt (eV): A unit of energy equal to the energy gained by an electron passing through a potential difference of 1 volt.

Enclosed beam system: An analytical X-ray system in which all possible X-ray paths (primary as well as diffracted beams) are fully enclosed.

Exempt shielded installation: An X-ray installation in which the source of radiation and all objects exposed to that source are within a permanent enclosure that meets the requirements of a shielded installation and contains *additional* shielding such that the dose equivalent rate at any accessible area 2 inches (5 cm) from the outside surface of the enclosure shall not exceed 0.5 mrem in any 1 hour.

Exposure: A measure of the ionization produced in air by X-ray or gamma radiation defined up to 3 MeV. It is the sum of the electrical charges of all of the ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in the air, divided by the mass of the air in the volume element. The unit of exposure is the roentgen (R) and is defined for photons with energy up to 3 MeV.

GLOSSARY (continued)

External surface: An outside surface of a cabinet X-ray system, including the high-voltage generator, doors, access panels, latches, control knobs, and other permanently mounted hardware, and including the plane across any aperture or port.

Fail-safe design: A design in which the failure of any single component that can be realistically anticipated results in a condition in which personnel are safe from exposure to radiation. Such a design should cause beam-port shutters to close, primary transformer electrical power to be interrupted, or emergence of the primary X-ray beam to be otherwise prevented upon failure of the safety or warning device.

Flash X-ray unit: A radiation-producing device that can produce nanosecond bursts of high-intensity X-ray radiation.

Fluorescence analysis: Analysis of characteristic X-rays and the X-ray emission process.

Incidental X-ray device: A device that emits or produces X-rays in the process of its normal operation, in which the X-rays are an unwanted byproduct of the device's intended use. Examples include video display terminals, electron microscopes, high-voltage electron guns, electron beam welders, ion implant devices, microwave cavities used as beam guides, radio-frequency cavities, microwave generators (magnetrons/klystrons), and field-emission electron beam diodes.

Intentional X-ray device: A device in which electrons undergo acceleration in a vacuum and collide with a metal anode target designed to produce X-rays for a particular application. Examples include diagnostic medical/dental X-ray devices, electron LINACs used in radiation therapy applications, portable and fixed flash X-ray systems, X-ray diffraction and fluorescence analysis equipment, cabinet X-ray systems, some Van de Graaff generators, and electron LINACs.

Interlock: A device for precluding access to an area of radiation hazard either by preventing entry or by automatically removing the hazard when the device is actuated.

GLOSSARY (continued)

Ionizing radiation: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, by interaction with matter, including gamma and X-rays and alpha, beta, and neutron particles.

Leakage radiation: Any radiation, except the useful beam, coming from the X-ray assembly or sealed source housing.

Normal operation: Operation under conditions as recommended by the manufacturer of an X-ray system or as specified by a written SOP. Recommended shielding and interlocks shall be in place and operable.

Open-beam system: An analytical X-ray system in which one or more X-ray paths (primary as well as secondary) are not fully enclosed.

Open installation: An industrial X-ray installation that, because of operational requirements or temporary needs, cannot be provided with the inherent degree of protection specified for other classes of industrial installations. Generally mobile or portable equipment where fixed shielding cannot be effectively used.

Port: In this context, an opening on the outside surface of the cabinet that is designed to remain open during X-ray production for the purpose of moving material to be irradiated into and out of the cabinet, or for partial insertion of an object that will not fit inside the cabinet.

Primary beam: The X-radiation emitted directly from the target and passing through the window of the X-ray tube.

Primary radiation: Radiation coming directly from the target of the X-ray tube or from the sealed source.

Rad (radiation absorbed dose): The unit of absorbed dose. One rad equals 100 ergs per gram.

GLOSSARY (continued)

Rem (roentgen equivalent man): The unit of dose equivalence used for humans, which considers the biological effects of different types of radiation. The dose equivalent in rem is numerically equal to the absorbed dose in rad multiplied by the applicable quality factor.

Roentgen (R): The unit of exposure. One roentgen equals 2.58 x 10^{-4} coulomb per kilogram of air.

Scattered radiation: Radiation that has been deviated in direction as a result of interaction with matter and has usually been reduced in energy.

Secondary radiation: Radiation (electrons, X-rays, gamma rays, or neutrons) produced by the interaction of primary radiation with matter.

Shielding: Attenuating material used to reduce the transmission of radiation. The two general types of shielding are primary and secondary. Primary shielding is material sufficient to attenuate the useful beam to the required level. Secondary shielding is material sufficient to attenuate stray radiation to the required level.

Shielded installation: An industrial X-ray installation in which the source of radiation and all objects exposed to that source are within a permanent enclosure.

Skyshine: Radiation emerging from a shielded enclosure which then scatters off air molecules to increase radiation levels at some distance from the outside of the shield.

Stem radiation: X-rays given off from parts of the anode other than the target, particularly from the target support.

Stray radiation: Radiation other than the useful beam. It includes leakage and scattered radiation.

GLOSSARY (continued)

Unattended installation: An industrial installation that consists of equipment designed and manufactured for a specific purpose and that does not require personnel in attendance for its operation.

Units: In accordance with 10 CFR 835.4, for all radiological units, the quantities used for records required by 10 CFR 835 shall be the curie (Ci), rad or rem. SI units, Becquerel (Bq), gray (Gy), and sievert (Sv) may be included parenthetically for reference to scientific standards, but are not authorized for required records. To convert conventional radiation units to SI units, the following factors are used:

1 rad = 0.01 gray (Gy)

1 rem = 0.01 sievert (Sv)

1 Ci = 3.7×10^{10} Bq

Useful beam: The part of the primary and secondary radiation that passes through the aperture, cone, or other device used for collimation.

Warning label: A label affixed to the X-ray device that provides precautions and special conditions of use.

X-ray device custodian: A person designated by line management as responsible for specific X-ray devices. This individual is responsible for designating the operators of specific X-ray devices, arranging for the operators to attend X-ray safety training, assisting in the development and maintenance of the X-ray device SOP, familiarizing operators with the X-ray device SOP, maintaining records of operator training and safety interlock checks, serving as the point of contact for the line organization's X-ray devices, and coordinating surveys with the X-Ray Device Control Office. An X-ray device custodian may also be an X-ray device operator.

X-ray device operator: An individual designated in writing by the X-ray-device custodian and qualified by training and experience to operate a specific X-ray device.

GLOSSARY (continued)

X-ray diffraction: The scattering of X-rays by matter with accompanying variation in intensity in different directions due to interference effects.

X-ray power supply: The portion of an X-ray device that generates the accelerating voltage and current for the X-ray tube.

X-ray source housing: An enclosure directly surrounding an X-ray tube that provides attenuation of the radiation emitted by the X-ray tube. The X-ray source housing typically has an aperture through which the useful beam is transmitted.

X-ray system: An assemblage of components for the controlled generation of X-rays.

X-ray tube: An electron tube that is designed for the conversion of electrical energy to X-ray energy.

X-ray tube assembly: An array of components typically including the cathode, anode, X-ray target, and electron-accelerating components within a vacuum.