Bioenvironmental Engineering Site Assessment I

Unit 9: Ionizing Radiation

Unit Description: For this unit, you will be stationed at Nooneberg AB in Kaiserslautern, Germany. During your assignment, you'll identify and analyze ionizing radiation health threats in a variety of situations. When you're done, you'll be able to explain the various situations where BE may encounter ionizing radiation health threats and how to control them.

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Lesson 1: Fundamentals and Effects of Ionizing Radiation

Lesson Description

In this lesson, you will present information to other BE Techs in your shop about ionizing radiation. Upon completion of this lesson, you will be able to describe the fundamentals of ionizing radiation and describe the biological effects of ionizing radiation.

Lesson Overview (Page 1 of 8)

Ionizing radiation has enough energy to change the atomic structure of matter and radiate energy through matter. It's important to be able to identify and analyze ionizing radiation health threats and recommend appropriate controls to protect personnel.

During your presentation at the BE shop's weekly meeting, you will:

- Describe basic principles related to ionizing radiation and radioisotopes.
- Define radioactive decay.
- Determine how different types of ionizing radiation interact with matter.
- Recall appropriate calculations that relate to ionizing radiation.
- Recall categories of effects associated with ionizing radiation.
- Associate potential biological effects to dose and types of ionizing radiation.

Audio Script

NCOIC: I'm scheduled to present information about ionizing radiation tomorrow at 13:00 during our weekly meeting; however, I just got word that I need to attend a briefing with the base commander at the same time.

I'd like you to present the information in my absence. You'll need to discuss the principles and biological effects of ionizing radiation with the other BE Techs in the shop. I'll email you the notes I prepared.

Scenario Challenge Point (Page 2 of 8)

In preparation to lead the meeting with the other BE Techs, you decide to review some basic terms associated with ionizing radiation that were included in your NCOIC's notes.

You will see several incomplete statements associated with ionizing radiation. Use the word bank to fill in the blanks that correctly complete the statement. Terms can be used more than once.

Audio Script

Narrator: Before your presentation, you need to make sure you understand the basic terms associated with ionizing radiation.

Word Bank

Isotope

Ionization

Radiation

Radioactive Decay

Radioisotope

Linear Energy Transfer

An element with the same number of protons, but different number of neutrons is known as a(n) ____________________.

This electron displacement, called ____________________ creates two electrically charged particles which may cause changes in living cells, plants, animals, and people.

Energy in the form of waves or moving subatomic particles emitted by an atom or other body as it changes from a higher energy state to a lower energy state is known as ____________________.

____________________ is the spontaneous disintegration or transformation of an atom in an attempt by that atom to reach a stable state.

A(n) ____________________ is an unstable ____________________ that, in an attempt to become a stable atom, emits energy in the form of ____________________.

____________________ is energy lost by particles along the path through which they are traveling.

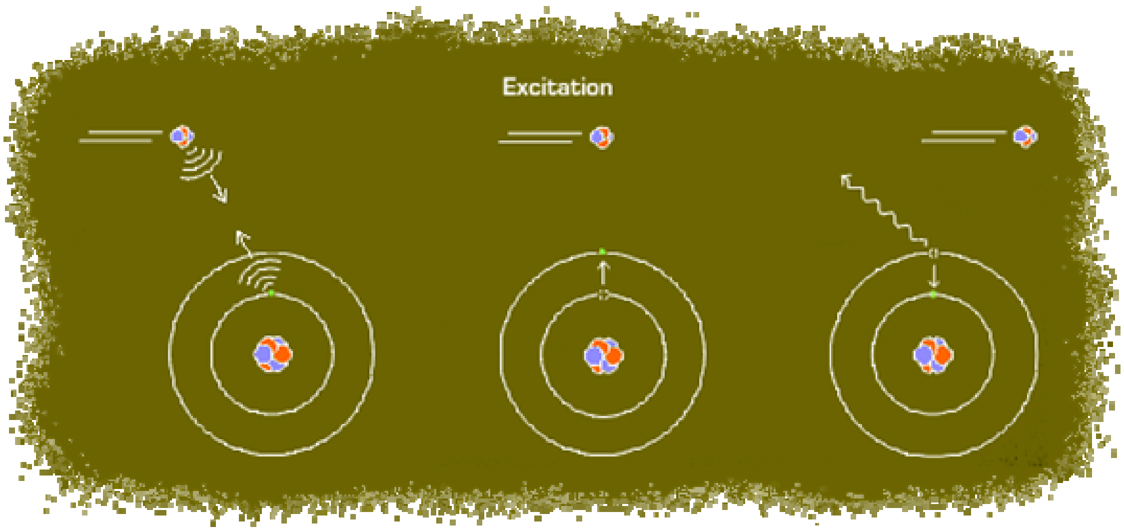
Ionizing Radiation Terminology (Page 2a of 8)

As you should recall, ionizing radiation is energy that can radiate through matter and change matter at a molecular level. Radiation is ionizing when an electron is stripped from an atom. When this ionizing radiation passes through materials, it carries enough energy to break, displace, or remove electrons from the atom. This electron displacement, called ionization, creates two electrically charged particles known as ions, which may cause changes in living cells, plants, animals, and people.

To fully understand the principles and potential health effects of ionizing radiation, you should know these basic terms.

Excitation

In contrast to ionization, excitation occurs when there is an addition of energy to an atomic system, changing the atom from a "ground" state to an excited state. The atom loses excess energy when an electron that is in a higher energy shell falls to the lower shell. When this occurs, the excess energy is released as a photon of electromagnetic radiation.



Radioactive Decay

An unstable atom will always attempt to return to a stable state. Radioactive decay is the spontaneous disintegration or transformation of an atom in an attempt by that atom to reach a stable state. The atom does not always decay directly to a stable state but may undergo a series of radioactive decays called a decay chain. Decay products are called "daughters" or progeny.

When an atom becomes unstable and starts to decay, it emits ionizing radiation.

Isotope

Isotopes are elements with the same number of protons, but a different number of neutrons. Such atoms are, in general, chemically indistinguishable. In other words, an isotope has the same atomic number, but a different atomic mass.

An example of an isotope commonly found at base level is H-3, or Tritium. This isotope of Hydrogen is used in Exit signs.

Nuclear Stability

There are only certain combinations of neutrons and protons within a nucleus of an atom that are considered stable. The appropriate neutron to proton ratio (n:p ratio) required for nuclear stability is different for each element. The majority of nuclei are stable if the number of protons equals the number of neutrons.

Linear Energy Transfer (LET)

Linear energy transfer (LET) is energy lost by particles along the path through which they are traveling. As a result, energy is transferred from the particle to the media (e.g., air, tissue). LET is primarily used to quantify the degree of damage caused along its path. Each type of radiation has varying degrees of LET.

Radioisotopes

Radioisotopes are unstable isotopes that, in an attempt to become a stable atom, emit energy in the form of radiation.

Different radioisotopes have different uses in industry and the Air Force.

Some examples of radioisotopes in the Air Force include:

- Cesium-137 (^{137}Cs), used to calibrate radiation detection equipment.
- Uranium-238 (^{238}U), called depleted Uranium, used in A-10 aircraft ammunition and as counterweights on various aircraft
- Nickel-63 (^{63}Ni), used in chemical warfare agent detection equipment (e.g., Automatic Chemical Agent Detection Alarm (ACADA)).

BE personnel must ensure personnel working with these materials do so in a safe

Radioactivity

If the atom of an element has an improper combination of protons and neutrons, the nucleus of the atom is at a higher energy level and is then said to be unstable. Radioactivity is the spontaneous emission of matter or energy from the nucleus of an unstable atom.

Ionizing Radiation and Interactions with Matter (Page 3 of 8)

All radiation is a form of energy. As described through LET, energy is lost by ionizing radiation along the path through which it is traveling. As a result, the energy from the interactions is transferred from the radiation to a medium. As this transfer takes place, the medium is affected. How the medium is affected is determined by the type of radiation. Also, the type of radiation impacts whether it is primarily an external or internal health threat. Read the information below to learn about ionizing radiation interactions with matter.

Tab: Alpha

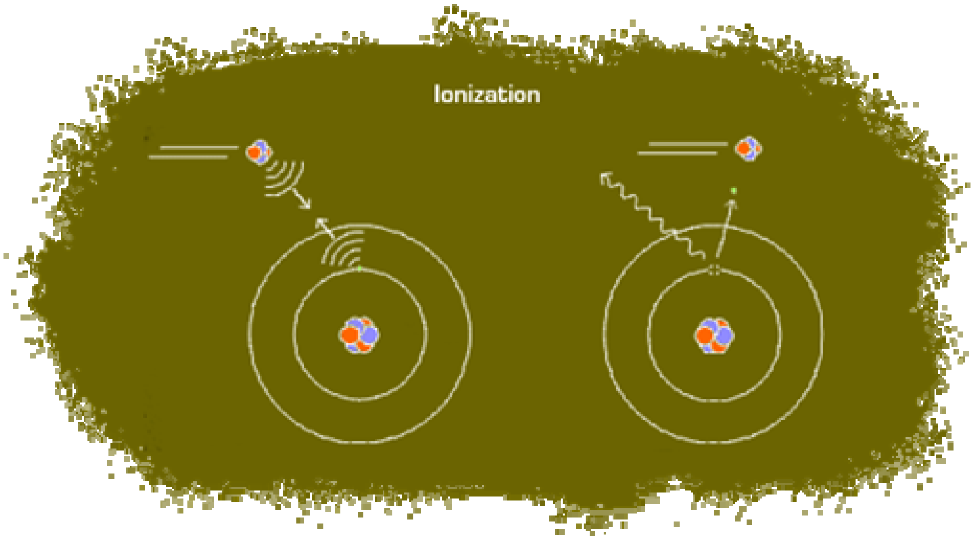
An alpha particle is formed when the n:p ratio is too low in the nucleus of an atom. An alpha particle consists of two neutrons and two protons and has a charge of +2. It is heavy and slow as compared to other types of radiation.

Due to their large size, the maximum distance alpha particles can travel through air is about 10cm. Alpha particles have a high LET, meaning they transfer large amounts of energy to an absorber while traveling through the medium. Most alpha particles can be stopped by paper or skin.

Alpha particles can interact with matter through **ionization** or **excitation**.

Ionization

Electrons are strongly attracted to alpha particles; in turn, electrons are ripped from the shell causing an ionizing effect.



Excitation

Excitation occurs when the particles are not close enough for ionization. This process transfers energy to the orbital electron. The electron jumps to the next higher orbit. The attractive forces lessen and the electron falls back to its lower orbit, releasing radiation energy.

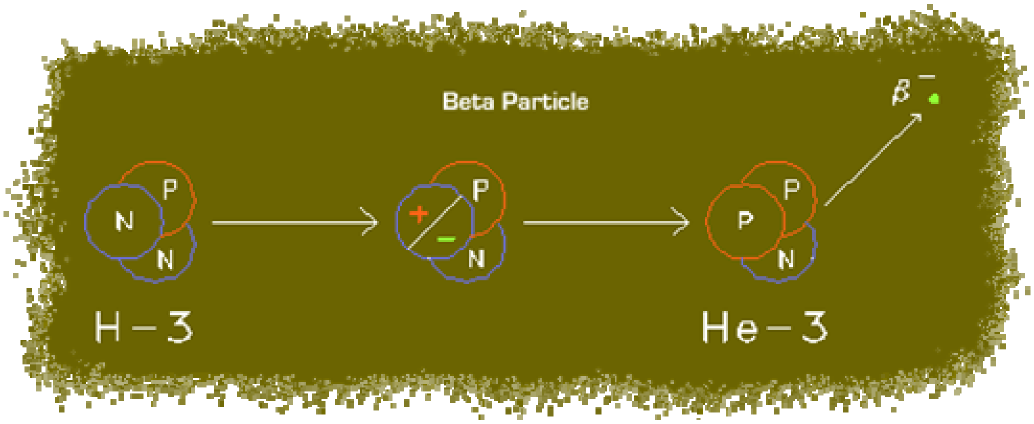
Tab: Beta

A beta particle, sometimes called a negatron, is identical in mass and charge (-1) to an electron. It is created when the n:p ratio of an element is too high, causing a neutron to change into a proton and a beta particle. When this occurs, the beta is simultaneously emitted and a new element is formed.

Because a beta particle is much lighter and faster than an alpha particle, it travels farther. However, the beta particle has less charge associated with it and therefore has less ionizing ability compared to the alpha particle. Therefore, the beta particle has a lower probability of interaction than an alpha particle and a much lower LET. These attributes make it less likely to suffer a "collision" or near collision with matter along a given length of path, allowing it to travel greater distances between collisions.

Beta particles can interact with matter through **ionization** and **bremsstrahlung.**

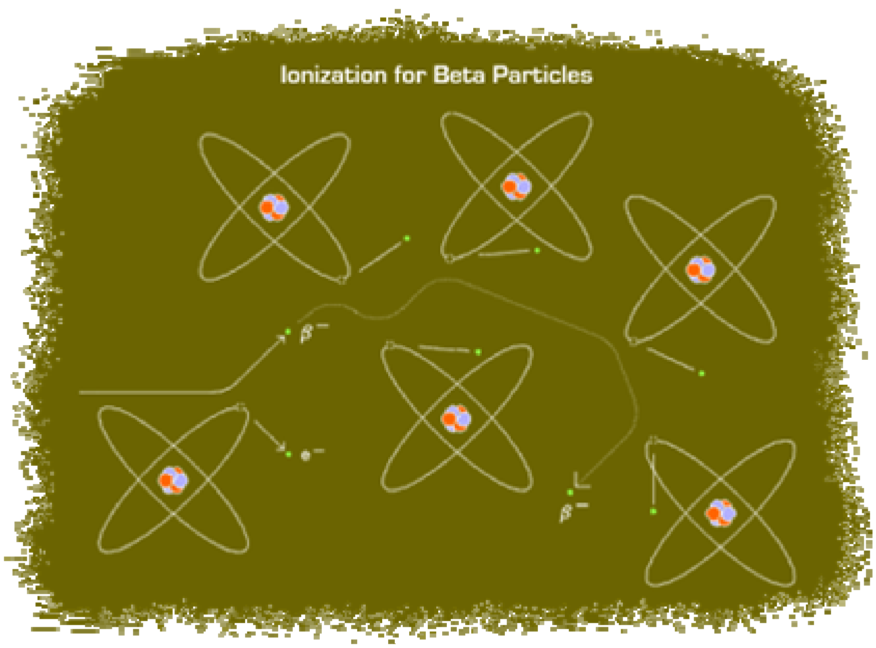
Another type of beta particle that can occur is the **positron.**



Ionization

Ionization occurs when beta particles interact with nearby atoms causing an electron to be removed, creating an ion pair.

The beta particle continues on its path of travel interacting along the way. As each interaction occurs, the beta particle loses kinetic energy. After a large number of ionization and excitation events have occurred, the beta particle slows and is eventually captured by an electron orbital, but not before creating thousands of ion pairs that will potentially interact with other atoms.

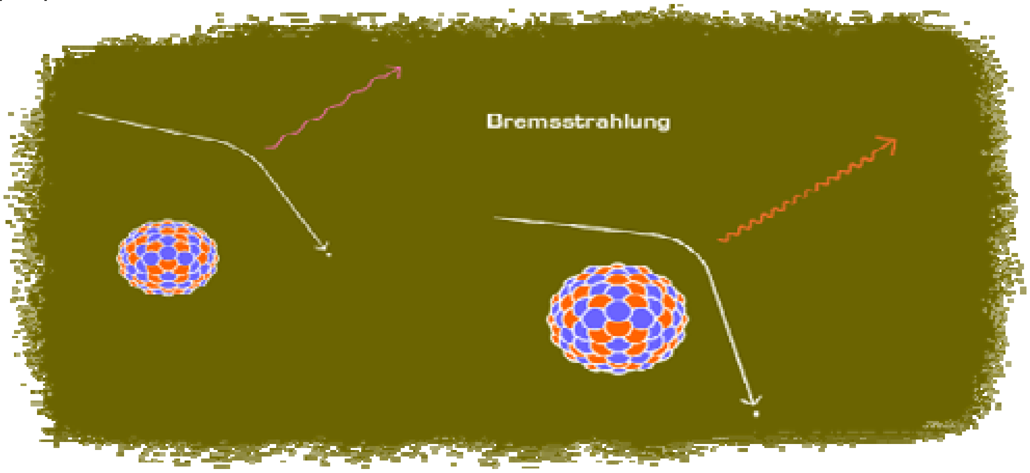


Bremsstrahlung

Bremsstrahlung is an interaction that causes a form of x-ray production in which high-speed beta particles penetrate the electron cloud and interact with the nucleus.

When this occurs, the attraction by the nucleus bends the beta's path and slows it down. When this slowing occurs, the beta particle undergoes a loss of kinetic energy. That loss of energy produces an x-ray. The energy of this x-ray varies and is dependent upon the amount of kinetic energy lost by the electron.

Medical departments use this process to generate x-rays for diagnostic purposes.



Positron

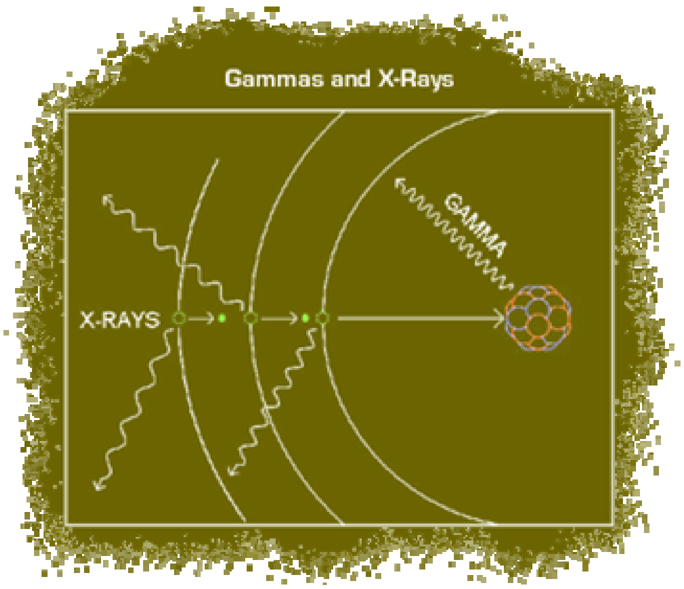
The positron is identical to a beta particle except that the charge is positive (+1). The positron is created when a proton changes into a neutron and a positron because there are too many protons in the n:p ratio. When the transformation occurs, the positron is ejected from the nucleus and a new element is formed with an atomic number that is lower by one.

In general, positrons have virtually the same penetration range as electrons but are annihilated when they collide with an electron. The only positron emitter found in the Air Force, aside from small check sources and accelerator-produced isotopes, is Fluorine-18 (^{18}F) which is used for nuclear medicine.

Tab: Gamma and X-Ray

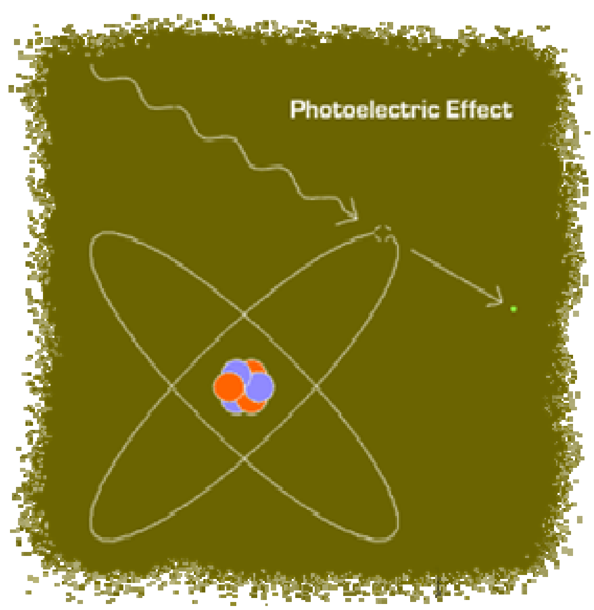
Gamma radiation is similar to x-ray because both are photons that have no mass or charge and travel at the speed of light. Unlike x-rays, gamma rays are emitted from the nucleus and result when the nucleus transitions from a higher to lower energy state. X-rays and gamma rays are the least ionizing and have the lowest LET but travel the farthest.

Gamma and x-rays interact with matter through the **photoelectric effect, Compton scatter, and pair production.**



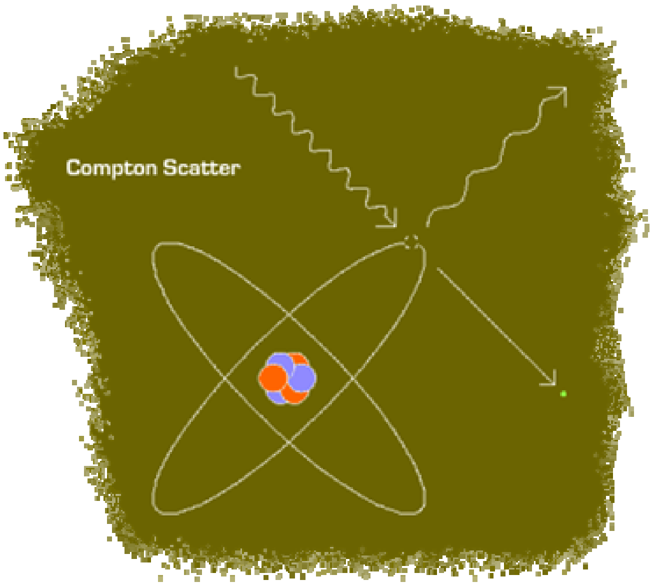
Photoelectric Effect

The photoelectric effect is an "all or none" energy loss where gamma rays impart all of their energy into an electron. The gamma photon vanishes and the electron is ejected. This effect predominately occurs at low photon energies.



Compton Scatter

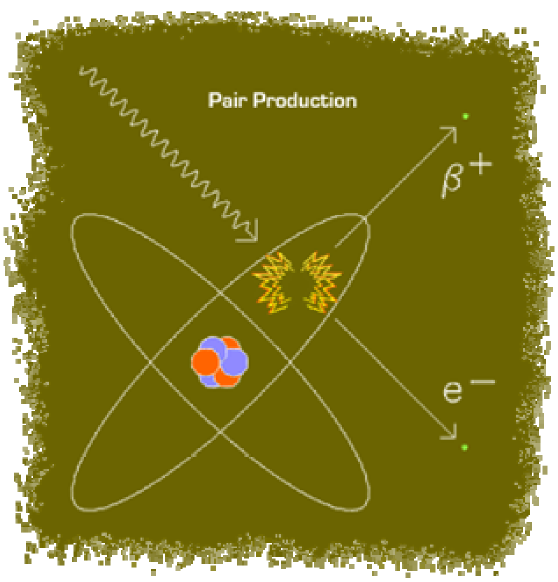
The Compton scatter is similar to the photoelectric effect but not all of the gamma energy is absorbed. This causes a weakened photon to be formed which will be a part of other Compton scatter or photoelectric events. Compton scatter occurs at all photon energies and in all materials. This means the potential for Compton scatter is always present.



Pair Production

Pair production is more rare than other gamma and x-ray interactions. It occurs with higher energy photons. In pair production, a photon disappears in the vicinity of a nucleus, and an electron and positron appear in its place. Any energy left over from their formation is shared by the two particles as kinetic energy, even though the energy is not always equal.

Additional ionizations may occur from interactions of the resulting electron and positron.

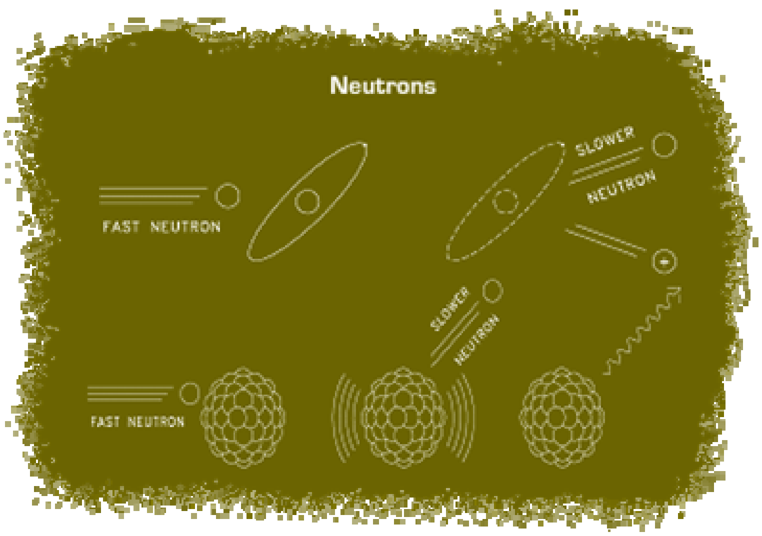


Tab: Neutrons

Neutrons are the most penetrating of all types of radiation. They are much less common than other forms of ionizing radiation and are formed from fission processes.

Unlike the alpha or beta, the neutron has no electrical charge. Neutrons have long or short ranges which are determined by the amount of kinetic energy present and how the neutrons were produced. The range of neutrons is also determined by the type of materials that they pass through.

Neutron emissions are not as commonly encountered in Air Force operations as other forms of radiation. Personnel might encounter a neutron source with an Americium-241 Beryllium (^{241}AmBe) source that is used in portable soil moisture density gauges which may be used by construction contractors or construction/engineering units. Intrinsic radiation is another form of neutron radiation produced from the **spontaneous fission** of Plutonium-240 (^{240}Pu) and Plutonium-238 (^{238}Pu) in nuclear weapons.



Spontaneous Fission

Spontaneous fission is a natural mode of decay in which nuclei disintegrate.

Appraisal (Page 4 of 8)

Match each type of ionizing radiation to the description of how it interacts with matter.

Type of Ionizing Radiation
Alpha
Beta
Gamma and X-ray
Neutron

	Description
____________________	Can interact through ionization or excitation
____________________	Can react through the photoelectric effect, Compton scatter, and pair production.
____________________	Can interact through ionization or bremsstrahlung.
____________________	Is the most penetrating of these types or radiation.

Quantifying Radiation and Radioisotopes (Page 5 of 8)

When it comes to surveying radiation and radioisotopes, the unit of measurement used to describe the **activity** of the radioactive material becomes very important. To summarize the relationship between quantities, units, and activity, keep in mind that higher activity yields more transformation per unit of time, which means more radiation is emitted. When the term "hot" is used to describe a radioactive source or sample, it typically refers to high levels of activity.

The units of activity used to quantify radiation and radioisotopes are:

- **Becquerel (Bq).**
- **Curie (Ci).**
- **Disintegration per second (dps).**
- **Disintegration per minute (dpm).**
- **Counts per minute (cpm).**

When quantifying radiation and radioisotopes, the ultimate goal is to determine exposure, dose, and appropriate controls when using radioactive material.

Activity

Activity is the number of disintegrations or transformations of radioactive material per unit of time (usually expressed in seconds). Activity can be mathematically expressed by using the following equation:

$$A = \lambda N$$

Where:
A = activity (expressed in disintegrations per second—dps)
λ = decay constant (seconds^{-1})
N = number of radioactive atoms decaying

You will use the following equation to determine the activity of a given radionuclide at any time, if you are given an initial activity.

$$A_t = A_o\, e^{(-\lambda t)}$$

Where:
A_o = original activity (curies or dps*)
e = 2.71828 (base of the natural logarithm system)
A_t = current activity (curies or dps*)
$T_{1/2}$ = radiological half-life
t = elapsed time between A_o and A_t

λ = decay constant simplified to: $\left(\frac{0.693)}{T_{1/2}}\right)$

*Units must be consistent.

Becquerel (Bq)

Becquerel is the international standard for the unit of measurement for activity.

1 Becquerel = 1 disintegration / second (dps).

Typically, multiples of this unit will be expressed in kilobecquerel (kBq) or gigabecquerel (gBq).

Curie (Ci)

1 Curie = 3.7×10^{10} disintegrations / second (dps).

Typically, measurements in this unit will be expressed in millicurie (mCi) or microcurie (µCi), or smaller.

Disintegration per second (dps)

The number of atoms that decay or transform in a given amount of material per second is expressed in disintegrations per second (dps).

Counts per minute (cpm)

The amount of radiation detected by an instrument each minute is expressed in counts per minute (cpm). Instruments that read in cpm are usually used to detect contamination. On a typical installation, alpha and beta particles and low level x-rays are measured in the unit of cpm.

Counts per minute are not equal to disintegrations per minute because the measurement probes are not 100% efficient. Disintegrations per minute can be estimated by dividing the counts per minute by the efficiency of the probe.

Scintillation probes are commonly used to detect activity. The amount of activity detected by the probe depends on the efficiency of the tube inside the detection equipment. Larger tubes will have better efficiency to detect the amount of activity.

Scenario Challenge Point (Page 6 of 8)

While presenting at the meeting, a new BE Tech in the shop asks you a question about the biological effects of radiation. Match each statement with the biological effects of ionizing radiation by marking the appropriate blocks in the table.

Description	Indirect Effects	Direct Effects	Acute Effects	Chronic Effects	Deterministic Effects	Stochastic Effects
Occur at the physical point of exposure and can immediately cause damage to any molecule.						
A certain minimum dose must be exceeded before the particular effect is observed.						
Often occur due to occupational exposures to many small doses over a period of 20 to 30 years or more.						
The probability of the effect increases with an increase in dose.						
Have both immediate and long-term effects since permanent damage has likely been caused.						
Occurs when cell damage is sustained from by-products of the exposure.						

Categories of Health Effects (Page 6a of 8)

Health effects of radiation exposure can vary greatly based on contributing factors such as type of radiation, dose, sensitivity of exposed cells and tissues, and the sensitivity of the individual. The effects of radiation exposure can be either acute or chronic and can occur both directly and indirectly. Select each tab to learn more about the categories of health effects.

Tab: Direct Health Effects

Direct health effects of radiation occur at the physical point of exposure and can immediately cause damage to any molecule. The effects that can occur from a direct exposure are:

- **DNA damage.**
- **Mutations in germinal cells.**
- **Mutations in somatic cells.**

DNA Damage

Direct damage to DNA occurs when radiation collides with or passes close enough to a molecule in the DNA to cause it to dissociate or break apart. This dissociation, caused by ionizing an atom on the DNA chain, may cause cell death or prevent the original gene information from being correctly transmitted to the next generation of cells**.**

Mutations in Germinal Cells

Direct effects of radiation exposure can cause mutations in germinal cells which cause the effects of the exposure to be passed on to descendants (a mutagenic effect).

Mutations in Somatic Cells

Direct effects of radiation exposure can cause mutations in somatic, or body cells, which create mutant daughter cells leading to abnormal growth of the cells (a carcinogenic effect).

Tab: Indirect Health Effects

Indirect effects of radiation exposure occur when a cell is not directly affected by exposure to radiation. Rather, damage is sustained from by-products of the exposure caused when the water of the body or of a cell absorbs the radiation.

Production of free radicals and compounds is an indirect effect of radiation exposure.

Production of Free Radicals and Compounds

Indirect effects of radiation exposure can cause the production of free radicals, which are chemically reactive fragments of molecules with unpaired electrons. Free radicals can change the body's chemistry so normal functions cannot proceed. These changes include:

- Reacting with proteins and nucleic acids.
- Deactivation of enzymes.
- Inhibiting cell division.

In general, free radicals can disrupt the cell membranes and damage cell performance, or they can recombine and be flushed out of the system.

Tab: Acute Effects

Effects of an acute radiation exposure can occur through single or multiple, high dose exposures over a short period of time. Acute exposures may have both immediate and long-term effects since permanent damage has likely been caused. Acute exposures can affect the:

- Circulatory System.
- Gastrointestinal System.
- Central Nervous System.

Tab: Chronic Effects

Effects of a chronic exposure to radiation often occurs due to occupational exposures to many small doses over a period of 20 to 30 years or more, causing the health effects to be delayed. Common effects of a chronic exposure may include:

- Skin cancer.
- Leukemia.
- Bone cancer.
- Lung cancer.
- Genetic effects.

Relationship Between Dose and Severity of Effects (Page 6b of 8)

When analyzing health effects associated with radiation, you should consider not only the category of effects, but also how the dose received relates to the severity of the biological effects.

The observable biological effects of ionizing radiation can be classified as either deterministic or stochastic based on the dose and response of the biological system to that dose.

Stochastic Effects

Stochastic effects are those effects that occur by chance among unexposed as well as exposed individuals. This means there is no direct relationship between the cause and the effects of the exposure. The only relationship between the dose and the effects is that the probability of the effect increases with an increase in dose. If an effect occurs, the severity of that effect is not impacted by the dose received.

The stochastic effect has a zero-threshold implication. This means there is no "safe" level of exposure and that even the smallest dose carries some health risk. The zero-threshold implication is the reason the As Low As Reasonably Achievable (ALARA) concept is used to protect Air Force radiation workers.

An example of a stochastic effect is being diagnosed with cancer. Cancers have a baseline occurrence, regardless of exposure status. Adding radiation exposure increases the probability that a specified individual would have cancer. However, that probability is extremely low. Conversely, someone who has never been exposed to ionizing radiation may have the exact same form of cancer.

Deterministic Effects

The severity of deterministic effects is directly related to the dose received.

Deterministic effects appear based on several assumptions:

- A certain minimum dose must be exceeded before the particular effect is observed.
- The magnitude of the effect increases with the size of the dose.
- There is a direct causal relationship between exposure to the radiation and the observed effect.

An example of a deterministic effect is cataract formation. The severity of the cataract, which includes the speed of onset, is directly related to the magnitude of the dose received by the corneal lens.

This effect can be seen in other non-radiation related situations also. For example, a person must exercise a certain amount of time before the effects are observed through responses such as increased heart rate and perspiration. As the person continues to exercise, these effects are increased due to the continuing work being performed.

Scenario Challenge Point (Page 7 of 8)

While presenting at the meeting, a student asks you a question about which types of radiation have the greatest biological effects. Place the types of radiation in order of *lowest* dose in REM to the *highest* dose in REM.

Word Bank	**List**	
Neutrons		Lowest Dose in REM
Gamma / X-Rays		⇓
Alpha particle		
Beta particle		Highest Dose in REM

Biological Damage and Forms of Radiation (Page 7a of 8)

Some forms of radiation are more capable of causing biological damage than others. However, to discuss potential biological effects, without consideration of the radiation type, the Roentgen Equivalent Man (REM) concept has been created. REM is the unit of radiation dose equivalent which takes into account the biological damage from exposure by assigning a **Quality Factor** to each type of radiation, based largely on its LET.

The REM equation is:

Radiation Absorbed Dose (RAD) x Quality Factor (Q) = Roentgen Equivalent Man (REM).

Quality Factor (Q)

The quality factor is a dimensionless quantity assigned to each type of radiation that allows doses to be normalized in relation to each other. Radiation types that have a higher LET have a greater effect on biological tissue and therefore have a higher quality factor.

Radiation Absorbed Dose (RAD)

The Radiation Absorbed Dose (RAD) is the amount of radiation absorbed by the tissue. This is important because the amount of radiation damage is proportionate to the amount of energy absorbed.

Radiation type	Dose in RAD	Q		Dose in REM
Gamma / X-Rays	10	1	=	10
Beta particles	10	1	=	10
Neutrons of unknown energy & high energy protons	10	10	=	100
Alpha particles	10	20	=	200

Tab: Alpha Particles

As you'll recall, alpha particles are the least penetrating type of radiation. The primary health threat from alpha particles occurs when an alpha-emitting isotope gets inside the body, such as by inhalation, and the radiation is able to do significant damage to the soft unprotected cells through which it passes.

The target organs for alpha particles are internal cells and tissues.

Tab: Beta Particles

Beta particles, you should recall, have a low penetrating ability. Therefore, the target organs for beta include skin if particles remain external to and in contact with the body, and internal cells and tissue if inhaled or ingested.

Tab: Neutrons

Neutron radiation is the most penetrating type of radiation, which makes protection from this radiation more difficult. The target organs for a neutron exposure are internal cells and tissues.

Tab: Gamma/X-Ray

Gamma and x-rays both have a high penetrating ability. Gammas and x-rays cannot be stopped just by a person's skin, unlike alpha or beta particles. Therefore, the primary target organs for gamma or x-ray exposure are internal cells and tissues.

Lesson Summary (Page 8 of 8)

You've learned that ionizing radiation occurs when unstable atoms go through a decay or transformation process in an attempt to reach a stable state.

Ionizing radiation is a significant concern because it can change matter at a molecular level and can cause significant direct, indirect, acute, and chronic health effects.

The observable biological effects of ionizing radiation can be classified as either deterministic or stochastic based on the dose and response of the biological system to that dose.

In this lesson you:

- Described basic principles related to ionizing radiation and radioisotopes.
- Defined radioactive decay.
- Determined how different types of ionizing radiation interact with matter.
- Recalled appropriate calculations that relate to ionizing radiation.
- Recalled categories of effects associated with ionizing radiation.
- Associated potential biological effects to dose and types of ionizing radiation.

Audio Script

Narrator: After reviewing your NCOIC's notes and presenting the information at the meeting, you allow the BE Techs to ask additional questions about the information they have learned. While answering questions, you take the opportunity to explain how this information will be important when assisting with monitoring radiation exposures of personnel on base. You also explain that next month's meeting will focus on ionizing radiation controls.

Lesson 2: Scatter Surveys

Lesson Description

In this lesson, you will be performing a scatter survey for new x-ray equipment being installed at an MFG on base. Upon completion of this lesson, you will be able to perform medical / diagnostic x-ray scatter surveys and interpret scatter survey results.

Lesson Overview (Page 1 of 10)

Scatter surveys provide important data needed to ensure personnel working with and around x-rays do not receive levels of radiation that could be harmful to them.

While completing the scatter survey and interpreting the results of the survey from the MTF, you will:

- Recall sources, use and production of x-rays.
- Determine why and when medical / diagnostic x-ray scatter surveys are performed.
- Recall steps for performing a medical / diagnostic x-ray scatter survey.
- Recall the medical / industrial scatter survey calculation.
- Perform appropriate ionizing radiation calculations.
- Recall the relationship of results to standards, mission accomplishment, and health effects.
- Compare survey results to standards for a given scenario.

Audio Script

NCOIC: I’ve just received a phone call from the MTF. They called to notify us they’re getting a new x-ray machine.

I need you to go to the MTF to conduct a scatter survey for the new equipment. Their x-ray tech, Mr. Kim, will be at the medical facility this afternoon to assist you with collecting your data.

Narrator: Before leaving the BE shop, you ask SrA Jones to assist you with conducting the survey.

Nooneberg AB Scenario (Page 2 of 10)

Audio Script

BE Tech: Good afternoon, Mr. Kim. I’m with Bioenvironmental Engineering and I’ll be conducting a survey for the area containing the new x-ray. This is SrA Jones. She’ll be assisting me today. It looks like you’ve been busy around here.

X-ray Tech: Sure have. A new addition to the MTF was just recently completed and we’re in the process of moving physicians’ offices from the existing part of the building to their new locations.

BE Tech: What happened to the other x-ray equipment that was in this area?

X-ray Tech: The old x-ray equipment owned by the MTF was moved from this area to the new section of the building because the new x-ray unit that has been installed was purchased by a group of orthopedic physicians who will be using nearby offices.

BE Tech: We're going to go ahead and get started. It will take us just a few minutes to get set up for the survey. I'm also going to take a look at some of the surrounding rooms.

X-ray Tech: All right, just let me know if you need my help.

Scenario Challenge Point (Page 3 of 10)

Before you proceed with conducting a scatter survey, you review the various sources and uses of x-rays that can be encountered in the Air Force with SrA Jones, a new BE Tech in the shop. You also explain how x-rays are produced from those sources.

Which two of the following are methods through which x-rays can be produced?

A Excitation

B Nuclear Stability

C Characteristic

D Bremsstrahlung

Sources and Uses of X-Rays (Page 3a of 10)

As you identify and analyze health threats and risks associated with ionizing radiation, you must consider the many ways in which Air Force personnel and members of the base community can be exposed to x-rays.

X-ray equipment is commonly used in therapeutic treatment of cancer patients and also in diagnostic medical and dental facilities.

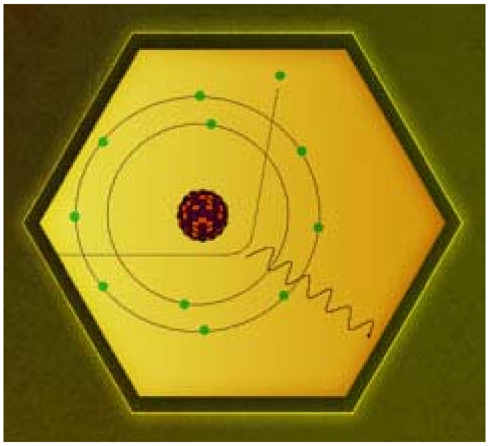
Production of X-Rays (Page 3b of 10)

Because you need to know how to control health threats and risks associated with x-rays, you must understand how they can be produced.

Bremsstrahlung

Bremsstrahlung x-rays are produced when high-speed electrons interact with a positive nucleus, causing a change in speed and direction. The result is a loss of kinetic energy in the form of an x-ray.

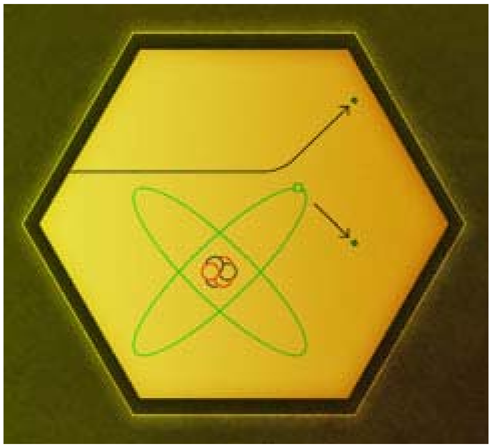
Bremsstrahlung is responsible for production of x-rays when shielding high-energy betas with lead. Since Bremstrahlung x-rays can be produced in this situation, high-energy beta emitters are often shielded with substances such as plastic to avoid additional production of x-rays.



Characteristic

Characteristic x-rays are produced when electrons backfill other electrons after they have been ejected from an atom. When this occurs, the free electron interacts with an orbital electron, and the repulsion forces of the two electrons push them away from each other before contact. The electron which is struck is ejected from the atom while the first electron continues on.

Characteristic x-rays stop being produced once the instrument is turned off.



Scenario Challenge Point (Page 4 of 10)

While SrA Jones goes to the truck to get the necessary survey equipment, Mr. Kim asks you why it's necessary to call BE any time a new piece of x-ray equipment is moved or purchased. You take the opportunity to explain the importance of ensuring not only the safety of the patients, but also of the personnel working around the equipment. Build a list of situations that would require a medical / diagnostic x-ray scatter survey to be performed.

Word Bank	List
A new office was places next to an exposure room.	____________________
A new x-ray technician has begun working on site.	____________________
A new x-ray unit was installed in the building.	____________________
Weekly compliance monitoring is being conducted.	
Film was changed after a patient x-ray	
Shielding changes have occurred.	

Performing Medical / Diagnostic X-Ray Scatter Surveys (Page 4a of 10)

As useful as x-rays can be for medical and dental facilities, it is important to ensure that the operation of the x-ray device is safe for personnel and patients.

BE is required to perform medical / diagnostic x-ray scatter surveys to ensure personnel do not exceed their annual dose limits which can cause adverse health effects and impact the performance of their mission.

They are also performed to help protect the general public from Air Force operations which produce radiation.

BE should conduct medical / diagnostic x-ray scatter surveys:

- **Upon initial acceptance of an x-ray unit.**
- **When conducting a baseline survey.**
- **For mandatory annual surveys.**
- **Any time modifications or changes in operation have occurred.**

Upon Initial Acceptance of an X-Ray Unit

Any time new x-ray equipment is accepted by the Air Force, an initial survey must be conducted prior to the device being put into use to ensure proper functioning of the equipment. All diagnostic x-ray equipment must meet accepted Air Force requirements and standards for ionizing radiation producing equipment. It is possible that initial acceptance is conducted by the vendor as part of the installation contract.

Conducting a Baseline Survey

A baseline survey should be conducted after a new x-ray unit is accepted by the Air Force and processes are ready to begin. A baseline survey not only assesses whether the equipment meets Air Force standards, but also evaluates the shielding for surrounding walls, doors, and windows.

Mandatory Annual Surveys

Mandatory annual surveys are conducted to determine whether there have been any changes with the operation of the equipment since the last survey and to ensure that the x-ray machine is still safe to operate. Annual surveys are required by AFI 48-148, *Ionizing Radiation Protection*. These surveys may consist of an operational review and, if no operational changes in equipment or controls have occurred, no specific measurements are required.

Modifications or Changes in Operation

Modifications or changes in operation of x-ray equipment may include:

- Shielding changes.
- X-ray unit changes.
- Changes in the expected maximum kVp mA.
- Changes in techniques of operation.
- Modifications to the room.
- Increase in workload.
- Changes to the use of surrounding rooms.

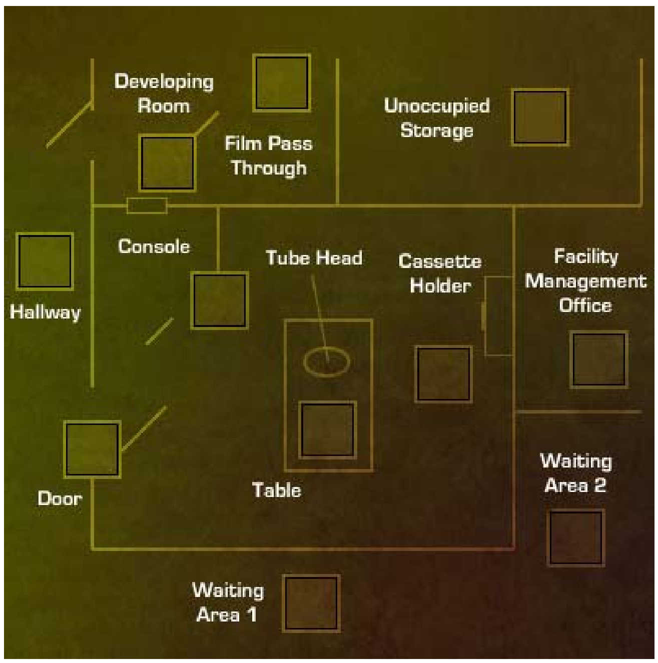
Scenario Challenge Point (Page 5 of 10)

You and SrA Jones begin preparation to conduct the scatter survey for the new x-ray equipment.

You begin sketching the x-ray room and adjacent areas. SrA Jones is working with Mr. Kim, detailing the instructions for setting up the x-ray, and obtaining the maximum and normal operating settings.

Since this x-ray is set up as a table configuration, SrA Jones asks Mr. Kim to set a 10" x 10" field.

While SrA Jones and Mr. Kim are setting up the field for the x-ray, you identify the areas around the exposure room where measurements should be taken. Using the sketch you have created and the associated list below, select the locations where you plan to collect measurements.



____	Hallway	____	Unoccupied Storage
____	Door	____	Cassette Holder
____	Developing Room	____	Facility Management Office
____	Film Pass Through	____	Waiting Area 1
____	Console	____	Waiting Area 2
____	Table		

Scenario Challenge Point (Page 6 of 10)

After setting up the meter, you and SrA Jones are almost ready to begin the survey. Below is your conversation with Mr. Kim, the x-ray technician.

Audio Script

BE Tech: Mr. Kim, I've set up the meter, and I think we're about ready to get started on the survey**.**

X-ray Tech: Okay, what do you need me to do?

BE Tech: Go ahead and start with the normal operating settings and we'll gather the data from the meter.

Narrator: Before proceeding, you notice that a step needed to conduct the survey has not been completed**.**

Which one of the following steps should be completed immediately before Mr. Kim turns on the x-ray?

A Conduct a mandatory inventory of the lead vests on site.

B Place a 1-gallon container of water in the beam or its equivalent.

C Place an additional meter on the table in the 10" x 10" field.

D Calculate the annual exposure rates for x-ray techs on site.

Steps for Performing Medical / Diagnostic X-Ray Scatter Surveys
(Page 6a of 10)

Once you have inventoried all x-ray equipment, documented the operation parameters, and determined what safety procedures are currently in place, you're ready to begin the actual survey process. You should follow specific steps and guidance outlined in the AFSC Form 3587 or equivalent. When performing an x-ray scatter survey for medical / diagnostic x-rays, you will survey **specific locations** in and around the exposure room.

Specific Locations

The primary locations you should be concerned with when conducting a scatter survey are the:

- Operator position.
- Edge of protective wall of operator position.
- Exposure room door.
- Walls in area adjacent to the exposure room 30 cm from the surface.
- Wall behind the chest cassette and the wall adjacent to or behind the panoramic unit for dental x-rays.
- Film pass-through if applicable.

Step 1

To begin the medical / diagnostic scatter survey, you should sketch the x-ray room and adjacent areas. Once you have sketched the area, you should label the measurement locations.

Step 2

Have the x-ray technician set up the unit using the following guidelines:

- Maximum / Normal Settings.
- Set a 10” x 10” field for a table x-ray or a 17” x 14” field for a chest x-ray.

Step 3

Place a 1-gallon container of water in the beam or the beam’s equivalent and set up your meter.

A 1-gallon container of water is used because it is the normal size of an x-ray beam and water is an inexpensive material that approximates human body tissue. This creates a situation where the x-rays scatter in the same direction when conducting a survey as during normal operating conditions.

Most meters are auto scaling; however, if the meter has a range selection, you should start at the low range.

Step 4

Instruct the technician to expose the container of water. Note the meter readings.

When you collect data for medical x-rays, you must take two sets of measurements. One set should be taken with the x-ray unit pointing toward the chest cassette and one set should be taken pointing toward the x-ray table.

As the technician exposes the water, you should make sure the peak exposure rates from the x-ray unit do not exceed the rating of your measurement instrument.

When you collect data for dental x-rays, you must also take two sets of measurements. One set should be taken for each direction the x-ray tube is pointing.

In addition, if an x-ray unit has a panoramic head, you must take measurements while it is operational.

Step 5

Monitor workers and adjacent areas for scatter and leakage of radiation. You should not take measurements inside the exposure room unless absolutely necessary, such as when procedures are performed in the exposure room that require personnel to accompany the patient. In general, the only measurement taken inside the exposure room is taken behind the shield and the edge of the shield.

Industrial Scatter Surveys (Page 6b of 10)

In addition to conducting medical / diagnostic scatter surveys, you may also be required to conduct industrial scatter surveys such as those for non-destructive inspection (NDI) operations.

While many tasks used for medical / diagnostic scatter surveys are also applicable for industrial scatter surveys, there are several primary differences.

For example, industrial scatter surveys are not typically required annually unless significant changes in operations occur from when a baseline or previous survey was conducted.

There are also differences with the collection of data. The instruments used for industrial surveys must often tolerate a longer exposure than those used for medical / diagnostic scatter surveys without damage to the measurement device.

By nature of industrial surveys, the x-ray operations may have multiple configurations which require separate measurements both in and around where the x-ray operations are taking place. Because industrial x-ray operations are not always conducted inside a building, appropriate measurement locations may not be readily apparent. Therefore, determining how far the beam reaches without confinement of walls is a critical task when conducting industrial scatter surveys.

Scenario Challenge Point (Page 7 of 10)

You and SrA Jones complete the survey at the medical facility and return to the BE shop. You review your notes, which state that the x-ray machine takes 75 table x-rays per day, and that the MTF is open 365 days per year. In your notes, you also recorded the following exposure data from the scatter survey:

- Console= 1.1 μR
- In hallway (at door)= 0.8 μR
- Waiting area 1= 0.2 μR
- Waiting area 2= 0.5 μR
- Facility management office= 2.5 μR

When determining annual exposure, assume a work-year of 2,000 hr (40 hr/wk x 50 wk), so the percentage of the year a worker will be exposed is (2,000 hr/yr)/(8,760 hr/yr).

Annual Exposure =

$$[(\text{Integrated Exposure } (\mu\text{R/Film})) \text{ X } (\text{Films/Year}) \text{ X } \left(\frac{1\,\text{mR}}{1000\,\mu\text{R}}\right) \times \left(\frac{2{,}000\ \text{hr/yr}}{8{,}760\ \text{hr/yr}}\right)] \text{ X OF}$$

Where: OF = Occupancy Factor

Note: Take measurements in integrated mode.

Using this information, what is the annual exposure for non-radiation personnel occupying the facility management office adjacent to the x-ray room?

Use an Occupancy Factor of 1 and round to the nearest whole number.

A 16 μR

B 16 mR

C 68 μR

D 68 mR

Medical / Industrial X-Ray Survey Calculation (Page 7a of 10)

After conducting the survey, you must determine what levels of annual exposure personnel surrounding the operating x-ray equipment may receive because of their proximity to the equipment.

This is determined by using the data from the scatter survey and the **Medical / Industrial X-Ray Survey Calculation** to calculate the annual exposure based on the **occupancy factor** for the exposure.

Medical / Industrial X-Ray Survey Calculation

The Medical / Industrial X-Ray Survey Calculation can be expressed using the following formula.

Annual Exposure =

$$[(\text{Integrated Exposure } (\mu\text{R/Film})) \text{ X } (\text{Films/Year}) \text{ X } \left(\frac{1\,\text{mR}}{1000\,\mu\text{R}}\right) \times \left(\frac{2{,}000\ \text{hr/yr}}{8{,}760\ \text{hr/yr}}\right)] \text{ X OF}$$

Where: OF = Occupancy Factor

Note: Take measurements in integrated mode.

Occupancy Factor

The occupancy factor takes into consideration how much time a person may be located in an area adjacent to operating radiation equipment.

For example, the amount of time spent in an occupied office is normally much greater than in a stairway. Therefore, the occupancy factor allows this difference to be accounted for when calculating the annual exposure for that area.

Once an annual exposure is calculated, if an occupancy factor should be considered, you should reduce the exposure of the calculated amount by the percentage indicated for that occupancy factor.

BEE Guide to Ionizing Radiation - 2005

TABLE 12-3 Occupancy Factors for Non-Occupationally Exposed Persons (NCRP 2004)

Occupancy Factor	Area
1	Administrative or clerical offices; laboratories, pharmacies, and other work areas fully occupied by an individual; receptionist areas, attended waiting rooms, children's indoor play areas, adjacent x-ray rooms, film reading areas, nurse's stations, x-ray control rooms
0.5	Rooms used for patient examinations and treatments
0.2	Corridors, patient rooms, employee lounges, staff rest rooms
0.125	Corridor doors
0.05	Public toilets, unattended vending areas, storage rooms, outdoor areas with seating, unattended waiting rooms, patient holding areas
0.025	Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop areas (unattended), attics, stairways, unattended elevators, janitor's closets

Medical / Industrial X-Ray Survey Calculation (Page 7b of 10)

Based on the information that you have already learned about the medical / industrial x-ray survey calculation, you will use the information below to practice calculating the annual exposure value for an x-ray technician working behind the operator's shield.

A dental facility performs 100 x-rays per week in a single configuration. The measurements taken from a scatter survey yields the following data:

- Waiting Area = 1.8 μR
- Restroom = 2.1 μR
- Adjacent Office = 0.8 μR
- In hallway = 2.4 μR
- Behind operator's shield = 1.2 μR

Annual Exposure =

$$[(\text{Integrated Exposure } (\mu\text{R/Film})) \text{ X } (\text{Films/Year}) \text{ X } \left(\frac{1\,\text{mR}}{1000\,\mu\text{R}}\right)\times\left(\frac{2{,}000\ \text{hr/yr}}{8{,}760\ \text{hr/yr}}\right)] \text{ X OF}$$

The dental facility performs 100 x-rays per week in a single configuration. The measurements taken from a scatter survey yields the following data:

- Waiting Area = 1.8 μR
- Restroom = 2.1 μR
- Adjacent Office = 0.8 μR
- In hallway = 2.4 μR
- Behind operator's shield = 1.2 μR

Step 1

To begin the medical / industrial survey calculation, you should determine which measurements you need from your scatter survey results to calculate the exposure for a given area.

In this example, since you are trying to determine the annual exposure for an x-ray technician who works behind the operator's shield, you should insert 1.2 μR into the calculation for the scatter reading (μR). This measurement represents the data collected from that area when the scatter survey was conducted.

Use the text field to practice completing this part of the equation.

Annual Exposure =

[(_._ (μR/Film)) X (Films/Year) X $\left(\frac{1\,\text{mR}}{1000\,\mu\text{R}}\right) \times \left(\frac{2{,}000\,\text{hr/yr}}{8{,}760\,\text{hr/yr}}\right)$] X OF

Step 2

Once you have input the scatter reading into the calculation, you will use the data collected from the scatter survey about x-ray usage to complete the number of films (or x-ray shots) per year.

In this example, the information you have regarding the usage is that the facility takes 100 shots per week on the x-ray.

To determine the number of shots per year, multiply the number of shots per week (100) by the number of weeks in a year (52). Based on this information, you determine the facility takes 5,200 shots per year.

Use the text field to practice completing this part of the equation.

Annual Exposure =

[(1.2 (μR/Film)) X (____) X $\left(\frac{1\,\text{mR}}{1000\,\mu\text{R}}\right) \times \left(\frac{2{,}000\,\text{hr/yr}}{8{,}760\,\text{hr/yr}}\right)$] X OF

The dental facility performs 100 x-rays per week in a single configuration. The measurements taken from a scatter survey yields the following data:

- Waiting Area = 1.8 μR
- Restroom = 2.1 μR
- Adjacent Office = 0.8 μR
- In hallway = 2.4 μR
- Behind operator's shield = 1.2 μR

Step 3

Once you have inserted the scatter reading and number of films per year into the calculation, you are ready to solve the bracketed portion of the equation.

First, multiply the scatter reading by the number of shots per year. You will divide that result by 1,000 to convert your answer to mR. You will then multiply your converted number by the percentage of the year a worker will be exposed. To do this you assume a work-year of 2,000 hours (40 hr/wk x 50 wk), which leads to a factor of (2,000 hr/yr) / (8,760 hr/yr), or 0.228.

In this example, after multiplying the scatter reading and the number of shots per year, you receive 6,240. Next, you should divide 6,240 by 1,000, then multiply by 0.228. This gives you an answer to the question of 1.42 mR.

Use the text field to practice completing this part of the equation.

Annual Exposure =

[(1.2 (μR/Film)) X 5,200 X $\left(\frac{1\,\text{mR}}{\_\_\_\_\ \mu\text{R}}\right) \times \left(\_.\_\_\_\right)$] X OF

Annual Exposure = [_.__ mR] X OF

Step 4

To complete the equation for the annual exposure, you need to consider what adjustment should be made based on the occupancy factor.

In this example, the area you are determining the annual exposure for is at an operator's position, the full calculated amount should be considered for the annual exposure based on the table shown below.

If the location you were calculating for was an unattended waiting room, for example, you would consider 5% of the calculated amount as the annual exposure.

Complete your calculation to determine the annual exposure for an x-ray technician who works behind the operator's shield by multiplying your previous answer by the appropriate occupancy factor.

Use the text field to practice completing this part of the equation.

_.__ mR = [1.42 mR] X _._

BEE Guide to Ionizing Radiation - 2005

TABLE 12-3 Occupancy Factors for Non-Occupationally Exposed Persons (NCRP 2004)

Occupancy Factor	Area
1	Administrative or clerical offices; laboratories, pharmacies, and other work areas fully occupied by an individual; receptionist areas, attended waiting rooms, children's indoor play areas, adjacent x-ray rooms, film reading areas, nurse's stations, x-ray control rooms
0.5	Rooms used for patient examinations and treatments
0.2	Corridors, patient rooms, employee lounges, staff rest rooms
0.125	Corridor doors
0.05	Public toilets, unattended vending areas, storage rooms, outdoor areas with seating, unattended waiting rooms, patient holding areas
0.025	Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop areas (unattended), attics, stairways, unattended elevators, janitor's closets

Scenario Challenge Point (Page 8 of 10)

After calculating the annual exposure for the non-radiation personnel, SrA Jones asks you a couple of questions about the next course of action.

You determined that non-radiation personnel occupying the facility management office receive an annual exposure of 16 mR.

Using the accepted exposure standard of 100 mR/yr for non-radiation workers in the MTF, does the annual exposure received represent a concern that requires further action?

A Yes

B No

If the annual exposure for the non-radiation workers did exceed the accepted standard, it would be a cause for concern. Which two of the following could you recommend as a next course of action in that instance?

A Relocate or rearrange the workspace of the non-radiation workers.

B Issue PPE to all non-radiation workers.

C Suspend all x-ray operations at the MTF.

D Relocate the cassette holder to an unoccupied storage wall and re-measure.

Scenario Challenge Point (Page 9 of 10)

Even though the dose being received by non-radiation personnel at the MTF is not above the accepted exposure standard, you decide to review your notes to determine whether personnel are receiving the lowest level of radiation possible from the x-ray machine.

The "As Low As Reasonably Achievable" (ALARA) concept is used to minimize the effects of radiation exposure even when exposure is below the occupational exposure limit. Which two of the following are examples of utilizing the ALARA concept?

A Establishing workplace action limits

B Utilizing portable x-ray units

C Reusing x-ray cassettes

D Posting warning signs

Relationship of Results to Standards, Mission Accomplishment, and Health Effects (Page 9a of 10)

When collecting data for scatter surveys, it's important to compare the results of the survey to appropriate standards and consider how the exposure can affect the mission and the health of personnel. Read the information below to learn more about the relationship of results to standards, mission accomplishment, and health effects.

Tab: Results

When analyzing the results of a scatter survey, you should consider data from **thermoluminescent dosimeters (TLD), survey meters,** and **electronic personal dosimeters (EPD)** as well as the results of appropriate calculations.

TLDs

TLDs gather data over a specific period of time and must be sent back to the laboratory for analysis.

Survey Meter

Survey meter results are dependent upon the meter type and detection method. However, data are available in nearly real time.

EPDs

Electronic personal dosimeter (EPD) results are shown instantly and can report in dose rate or total dose. The device alarms can be programmed for a certain dose rate and/or total dose.

Tab: Standards

After analyzing the results, you must compare them to the most stringent standard available. The primary standard used by the Air Force for radiation health threats is the AFI 48-148, *Ionizing Radiation Protection* or other limit as specified by the BEE/RSO.

You should also follow the **"As Low As Reasonably Achievable" (ALARA) concept** to further minimize health risks from cumulative radiation exposure.

ALARA Concept

The ALARA concept should be used when designing or modifying work areas, including determination of the appropriate material and thickness for shielding. BE uses this concept to ensure adequate radiation safety is incorporated into the design plan of new facilities. Regardless of the standard, you should always try to keep the exposure to personnel as minimal as possible.

Examples of the use of the ALARA concept include:

- Installing safety mechanisms (e.g. system interlocks).
- Controlling access to the exposure room in order to prevent someone from entering the room during an exposure.
- Posting warning signs.
- Providing annual training.
- Issuing appropriate PPE (e.g. lead aprons).
- Following proper procedures.
- Performing proper maintenance of the x-ray unit.
- Workplace / process specific action limits.

Tab: Mission

The accomplishment of the Air Force mission requires the use and exploitation of ionizing radiation. Minimizing radiation exposure to Airmen is the most effective strategy to reduce negative impact on the mission.

In medical and industrial x-ray environments, proper procedures and monitoring helps minimize or even completely eliminate negative impact on the mission. In certain situations, if overexposure occurs, an individual's ability to contribute to the mission may be affected.

For example, if a person is performing the same job after hours in the civilian sector, the combined exposures must not exceed the standard. If the exposures exceed annual limits, the person may not be permitted to perform the work for the remainder of the annual cycle, significantly affecting the mission. In order to address this concern, personnel working around x-rays are required to provide the Air Force a copy of the results from all their exposures to determine their total annual exposure.

Tab: Health Effects

Radiation exposure standards are more than just limits that are followed to avoid legal ramifications. They exist to protect personnel and the general public from overexposures which can cause significant health effects. One of your primary responsibilities as part of BE is to protect the health of Air Force personnel and the base community.

Air Force personnel must be confident that radiation exposures are being controlled. Minimizing health effects related to radiation exposure will also reduce the impact to the accomplishment of the mission, because when people are healthy, they can perform their duties. The ALARA concept should be employed with this relationship between results, standards, mission accomplishment, and health effects in mind.

Lesson Summary (Page 10 of 10)

Because of the potential health effects associated with x-rays, it is important to be able to identify how x-rays are produced and how they are used in the Air Force. X-rays are commonly found in medical, dental, and veterinary facilities.

Medical / diagnostic x-ray scatter surveys must be performed and the annual exposure to personnel calculated to ensure that it remains below accepted standards.

Results above accepted standards can have detrimental effects to both the health of personnel and the accomplishment of the mission.

In this lesson you:

- Recalled sources, use and production of x-rays.
- Determined why and when medical / diagnostic x-ray scatter surveys are performed.
- Recalled steps for performing a medical / diagnostic x-ray scatter survey.
- Recalled the medical / industrial scatter survey calculation.
- Performed appropriate ionizing radiation calculations.
- Recall the relationship of results to standards, mission accomplishment, and health effects.
- Compared survey results to standards for a given scenario.

Audio Script

Narrator: After performing the scatter survey, your BEE collected additional data that confirmed the scatter survey results. The non-radiation workers in the adjacent facility management office were moved to a new location in another part of the MTF. Appropriate shielding was installed in the wall to control any accidental x-ray exposures, and the area is now used for archived document storage.

Lesson 3: Performing an Ionizing Radiation Overexposure Investigation

Lesson Description

In this lesson, you will be completing an overexposure investigation for an incident that has occurred at an NDI shop on base. Upon completion of this lesson, you will be able to perform a suspected ionizing radiation overexposure investigation.

Lesson Overview (Page 1 of 7)

Ionizing radiation overexposure investigations are used to collect information and document situations where personnel may have been exposed to levels of ionizing radiation that exceed accepted standards and could cause damaging health effects.

While completing the suspected overexposure investigation at the non-destructive inspection (NDI) shop, you will:

- Determine why and when suspected ionizing radiation overexposure investigations are performed.
- Recall procedures for investigating suspected ionizing radiation overexposures.

This lesson should take you approximately 10 minutes to complete.

Audio Script

RSO: I've received a call from the supervisor of the NDI shop. One of the workers has reported a suspected overexposure. We need to begin an investigation immediately. I'll contact USAFSAM. Go ahead and begin prep, and I'll meet up with you in a little bit.

Scenario Challenge Point (Page 2 of 7)

With little preliminary information available about the suspected overexposure, you begin your work on the investigation by considering several instances when an overexposure investigation is required. Which two of the following situations would prompt an overexposure investigation?

A An individual's electronic personal dosimeter (EPD) registered above 30 mR.

B A radiographic supervisor suspects someone has been overexposed in the shop.

C A damaged survey meter is returned with normal exposure readings.

D The x-ray equipment has been transported to a new area on base for repairs.

E An individual's thermoluminescent dosimeter (TLD) results are greater than 500 mR.

Abnormal Exposures and Overexposures (Page 2a of 7)

As useful and beneficial as certain types of ionizing radiation can be, they can also be extremely harmful if personnel are overexposed to the radiation. Any time suspected **abnormal exposures** or **overexposures** occur, they are treated as high priority situations, and an investigation is conducted.

A specific base or MTF may establish acceptable exposure levels that are lower than the published standard to achieve ALARA. In order to confirm these levels, an investigation may also be performed.

Abnormal Exposures

Any dosimeter and/or bioassay result exceeding the monthly or quarterly values in Table 1 of AFMAN 48-125, *Personnel Ionizing Radiation Dosimetry* represents an abnormal exposure.

TABLE 1. Abnormal Exposures Criteria

The More Restrictive Of	Monthly Dosimeter Value	Quarterly Dosimeter Value
Total Effective Dose Equivalent	> 4.17 mSv (0.417 rem)	> 12.5 mSv (1.25 rem)
Deep dose equivalent to pregnant radiation worker	> 0.5 mSv (0.05 rem)	N/A
Sum of deep dose equivalent and committed dose equivalent to any individual organ or tissue other than the lens of the eye	> 41.7 mSv (4.17 rem)	> 125 mSv (12.5 rem)
Eye dose equivalent	> 12.5 mSv (1.25 rem)	> 37.5 mSv (3.75 rem)
Shallow dose equivalent to skin or extremity	> 41.7 mSv (4.17 rem)	> 125 mSv (12.5 rem)
Internal deposition of any radionuclide	> 10% of Annual Limit on Intake (ALI)	> 25% of ALI

Overexposures

An overexposure occurs when the dosimeter results exceed the annual dose limits contained in Table 2 of AFMAN 48-125, *Personnel Ionizing Radiation Dosimetry*.

TABLE 2. Potential Overexposure Criteria

The More Restrictive Of	Value
Total Effective Dose Equivalent	> 0.05 Sv (5.0 rem)
Total effective dose equivalent to pregnant radiation worker during course of pregnancy	> 0.005 Sv (0.500 rem)
Sum of deep dose equivalent and committed dose equivalent to any individual organ or tissue other than the lens of the eye	> 0.5 Sv (50 rem)
Eye dose equivalent	> 0.15 Sv (15 rem)
Shallow dose equivalent to skin or extremity	> 0.5 Sv (50 rem)
Internal deposition of any radionuclide	> of applicable ALI

Overexposure Investigations (Page 2b of 7)

Generally, the following events will trigger suspected overexposure investigations:

- An individual’s thermoluminescent dosimeter (TLD) results are greater than 500 mR.
- An individual’s electronic personal dosimeter (EPD) in non-destructive inspection (NDI) situations alarms above 500 mR.
- A radiographic supervisor suspects someone has been overexposed.
- A survey meter is returned with readings over the overexposure limit.

When an overexposure occurs in an occupational setting, the individual (or individuals) who have been potentially overexposed will cease all radiographic operations and report the incident to the shop supervisor or the base RSO.

The base RSO will immediately notify the **USAFSAM / ESOH Service Center**, the MAJCOM BEE, and AFMSA/SG3PB.

USAFSAM / ESOH Service Center

After notification by the RSO, USAFSAM will immediately provide facsimile instructions for performing an investigation, including any bioassay requirements. USAFSAM will also request the base RSO to return any dosimeters and/or bioassays in progress at the time of suspected overexposure to USAFSAM for priority processing.

Once processing has been complete, USAFSAM will immediately report the results to the installation RSO by telephone and either facsimile letter or encrypted email.

Purpose of an Overexposure Investigation (Page 2c of 7)

Once it's determined a suspected overexposure has occurred, an overexposure investigation is initiated.

An overexposure investigation is conducted to:

- Confirm that an overexposure has occurred.
- Determine the levels of radiation to which personnel were exposed.
- Identify the need for treatment of associated health effects, if applicable.
- Attempt to prevent recurrences of overexposures.

Nooneberg AB Scenario (Page 3 of 7)

After contacting the USAFSAM / ESOH Service Center, the RSO comes by the office where you're working to check on the progress of the investigation.

Audio Script

RSO: Hello, Sergeant. What do we know about the incident so far?

BE Tech: Well, we don't have much information yet, except that there was only one person involved.

RSO: Have we received the fax from USAFSAM yet with the procedures for the suspected overexposure investigation?

BE Tech: Yes sir, it just came in.

RSO: Go gather the things we'll need from the equipment room and meet me at the truck in 15 minutes. The shop supervisor is expecting us within the hour.

BE Tech: Yes sir, I'll meet you there.

Scenario Challenge Point (Page 4 of 7)

When you and the RSO arrive at the NDI shop, you speak with the supervisor to begin collecting data about the incident. You learn that the individual was standing in direct line of exposure when the x-ray was accidentally triggered by a malfunctioning part of the device. Build a list of the information you should be able to determine based on your data collection of the incident.

Word Bank	List
The type of work being performed in the shop.	______________________________
The circumstances surrounding the abnormal exposure.	______________________________
Any controls that are currently in place and operation properly.	______________________________
The number of people who have come in contact with the individual	______________________________
The portion of the individual's body exposed.	
The validity of the dose received.	
Any corrective actions required to prevent a recurrence.	

Collecting Incident Information (Page 4a of 7)

To begin the base RSO's formal investigation, information about the potential overexposure will be collected from all parties involved. The information is used to determine:

- **The circumstances surrounding the suspected overexposure.**
- **The validity of the dose received.**
- **Any corrective actions required to prevent a recurrence.**

The Circumstances Surrounding the Suspected Overexposure

When documenting the circumstances surrounding the overexposure, complete a detailed sketch that includes the positions of personnel and any additional information related to the incident. You should also record the settings of the radiographic equipment at the time of exposure.

It's also important to use information from the individual or individuals exposed to reestablish the exact positions of all objects at the time of the incident.

The Validity of the Dose Received

The primary method of validating the dose is to compare the actual dose received by the exposed individual and the reported results, by collecting the individual's TLD badge and issuing a new badge while waiting for TLD results. This is done to help confirm an overexposure and determine whether the individual may be at risk for health effects.

Any Corrective Actions Required to Prevent a Recurrence

The base RSO uses data gained from the overexposure investigations to formulate recommendations for controls or other corrective actions that could prevent future overexposures to personnel.

Recreating the Incident (Page 4b of 7)

As a part of collecting the data for the investigation, you should attempt to recreate the incident. Using dosimeters, the x-ray/radionuclide apparatus, and the same techniques used during the incident, expose the dosimeters and record the instrument readings.

Recreating the incident allows you to mirror the circumstances of the overexposure incident and determine the actual cause and potential effects of the overexposure. This process also serves as an additional method for validating the dose received.

Nooneberg AB Scenario (Page 5 of 7)

By recreating the incident, you were able to confirm that the individual who was standing in direct line of exposure when the x-ray device was accidentally triggered recorded a TLD reading of 0.035 Sv (3.5 REM). Based on this and other information you and the RSO have gathered, you determine that an actual overexposure has occurred.

Scenario Challenge Point (Page 6 of 7)

After you and the RSO have determined that an actual overexposure has occurred, you begin work on the incident report.

Answer the following questions about the incident report for the overexposure investigation at the NDI shop.

How long from the time of the overexposure incident do you have to submit the investigation report?

A 5 days

B 7 days

C 15 days

D 30 days

Since you are working with an NDI overexposure incident, to which two of the following offices should you send copies of the incident report?

A USAFSAM

B Air Force NDI Office

C Emergency Management

D Public Health Office

Completing the Report (Page 6a of 7)

Documenting the incident properly is an important step in concluding the overexposure investigation. Once the incident data has been collected, the base RSO must obtain a written and signed statement from the involved individuals concerning their actions which resulted in or contributed to the overexposure.

The base RSO will submit a **written report** of the investigation's **findings** to USAFSAM within the **allotted time period.** The report includes the signed statements of involved individuals which will indicate whether they are in agreement with the report.

Written Report

The written report documenting the overexposure must include the:

- Identity of the person(s) exposed.
- Circumstances surrounding the exposure.
- Estimates of the individual's dose, including how the dose was determined.
- Portion of the body exposed.
- Cause of the exposure.
- Results of medical examination(s).
- Corrective actions taken.
- Signed statements supporting or contesting the investigation report.

The Investigation's Findings

If the final investigation report determines an overexposure has occurred, USAFSAM approval must be obtained before any exposed individual is allowed to return to radiation-related duties.

When the investigation is related to a Non-destructive Inspection (NDI) overexposure, a copy of the investigation report should also be sent to the AF NDI office at Tinker AFB.

Allotted Time Period

If the radiation exposure is considered an abnormal exposure, 30 days from the date of exposure are allowed to complete the report and submit the findings to USAFSAM.

If the exposure is considered an overexposure, 7 days from the date of notification are allowed to complete the report and submit the findings to USAFSAM.

Lesson Summary (Page 7 of 7)

Any time a suspected abnormal exposure or overexposure occurs, it is treated as a high priority situation, which initiates an investigation to confirm the abnormal or overexposure and determines the appropriate course of action (COA).

Once the incident is reported and the RSO initiates the investigation, data are collected which are used to recreate the situation and to determine the actual exposure.

At the conclusion of the investigation, a report is created which details the information surrounding the incident. When an overexposure is an NDI incident, a copy of the report is also sent to the NDI office at Tinker AFB.

In this lesson you:

- Determined why and when suspected ionizing radiation overexposure investigations are performed.
- Recalled procedures for investigating suspected ionizing radiation overexposures.

Audio Script

Narrator: The incident report for the NDI overexposure was completed and sent to USAFSAM and the NDI office at Tinker Air Force Base. The worker who was exposed is undergoing medical monitoring to identify any associated health effects from the exposure. USAFSAM has not granted approval for the individual to return to x-ray operations.

Lesson 4: Ionizing Radiation Threat Control Options

Lesson Description

In this lesson, you will be making recommendations for controls at the NDI shop that has just completed remodeling. Upon completion of this lesson, you will be able to develop ionizing radiation threat control options.

Lesson Overview (Page 1 of 10)

Recommending appropriate health controls is an important part of your responsibilities during the HRA process. While developing ionizing radiation threat control options for the NDI shop on base, you will:

- Recall control requirements for ionizing radiation.
- Recall principles of dose, dose rate, and time related to ionizing radiation.
- Determine appropriate controls for ionizing radiation.
- Recall appropriate calculations that relate to ionizing radiation.
- Perform appropriate ionizing radiation calculations.

Audio Script

RSO: The NDI shop recently went through an overexposure investigation. The final report recommended controls in the shop undergo further evaluation, once remodeling efforts in progress at the time were completed, to ensure they are effective. I need you to perform an assessment of the current controls at the shop and make recommendations on any modifications which may need to be made.

Nooneberg AB Scenario (Page 2 of 10)

When you arrive at the NDI shop, you examine the layout of the area. Some new construction on the shop is being finished. From speaking with CE personnel onsite, you learn that the current plans for shielding around an office in the shop will be installation of a composite plastic under the sheetrock. You make note of this plan and continue your inspection of the site.

Nooneberg AB Scenario (Page 3 of 10)

While continuing your assessment of the shop, you stop to speak with a worker who uses the NDI x-rays to perform inspections.

Audio Script

Worker: Hi, how can I help you today?

BE Tech: Well, I'm here to review the remodeling of the NDI shop and ensure that proper controls are in place. Looking at the layout of the shop, I have a few questions. Will personnel be located in the office space opposite the NDI control room?

Worker: Yes, that area will be used for personnel from the education center. They'll be moving in at the end of the month.

BE Tech: I noticed the x-ray machine is portable. Is it moved around the shop, or does it normally remain in one location?

Worker: We move the x-ray equipment according to the type of inspection being conducted.

BE Tech: Thanks for the information.

Worker: You're welcome. Let me know if you need anything else.

Scenario Challenge Point (Page 4 of 10)

As you continue your inspection, you consider the most appropriate methods for controlling radiation health threats in the NDI shop.

Match each control with its appropriate description by marking the appropriate blocks in the table.

Description	Distance	Shielding	Time
The first method that should be used to control exposures.			
Usually the easiest control method to apply.			
Provides a physical barrier to absorb radiation energy.			

Control Requirements for Ionizing Radiation (Page 4a of 10)

Being able to effectively protect personnel from potential health effects of radiation by using appropriate controls is important to the success of the mission. Select each tab to learn how ionizing radiation can be controlled using engineering, administrative, and PPE control methods.

Tab: Engineering Controls

The primary engineering control used for radiation health threats is shielding. Shielding is arguably the most important method of controlling radiation exposures because it provides a physical barrier to absorb the radiation energy and can be used when other engineering or administrative controls may not be feasible.

Other engineering controls may include:

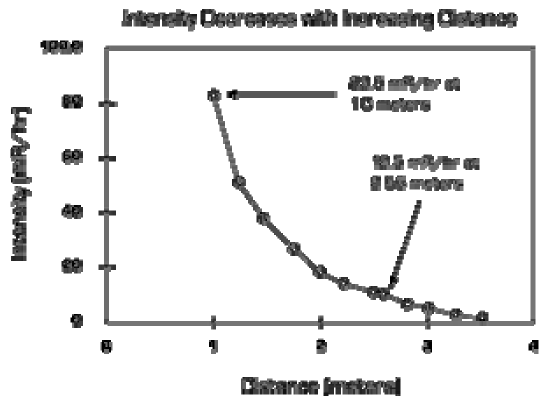
- Visible and audible warning signals.
- Access interlock systems that interrupt the power to an x-ray console if the interlock is broken.
- Emergency shut-off switches that are readily visible.

Tab: Administrative Controls

Administrative controls include the use of **time**, **distance**, **contamination control**, training, and use of the **As Low As Reasonably Achievable (ALARA)** concept.

Other examples of administrative controls include:

- Restricting access during operations that can cause radiation.
- Posting safety monitors designed to monitor restricted areas where other controls are not practical.
- Requiring annual refresher training for radiation safety workers.



Time

Time, an administrative control, is the first method that should be used to control exposures because of the proportional relationship radiation doses have with the time spent in a radiation field. By limiting the exposure time to radiation, you reduce the dose of radiation received by personnel.

You can calculate the dose received based on the duration of exposure by using the following formula:

$$\frac{exposure\left(\frac{mR}{hr}\right) \times time[min]}{60\,\frac{min}{hr}} = Dose[mR]$$

Distance

Distance is a very effective administrative control method and usually the easiest to apply. Distance can be described using the inverse square law which applies to the attenuation of gamma and x-ray point sources in air. The inverse square law states that exposure rate is inversely proportional to the square of the distance from the point source, meaning the intensity of exposure is decreased by increasing distance.

The inverse square can be calculated using the following formula:

$$I_1 \times D_1^2 = I_2 \times D_2^2$$

Where:

D_1 = Distance 1

D_2 = Distance 2

I_1 = Intensity at D_1

I_2 = Intensity at D_2

Contamination Control

Contamination control becomes an important administrative practice for controlling exposures to radioactive materials and spills. A spread of contamination can easily occur when personnel involved in a spill or spill clean up move to various locations. You can prevent the spread of contamination by restricting the movement of personnel and conducting monitoring to verify that they are free of any contamination before relocation is allowed.

If a minor spill occurs, it can be handled safely by the lab staff without safety or emergency personnel. All other types of spills are considered emergency situations. In any case, personnel should notify the RSO to ensure awareness of the spill and proper procedures are followed to clean it up.

ALARA Concept

BE uses this concept to ensure adequate controls for radiation health threats and that radiation exposures are kept as minimal as possible.

Tab: Personal Protective Equipment

Personal Protective Equipment (PPE) should be used as a last resort when other forms of controls are not feasible. When determining the appropriate PPE, you should ensure there is an adequate supply of PPE such as aprons, gloves, movable barriers, and leaded glasses available in each exposure room.

For each piece of radiation PPE, documentation about proper use and maintenance, to include inspection for cracks and holes, must be available for review. It is also important to ensure proper storage of the PPE.

Appraisal (Page 5 of 10)

Use the following example to practice calculating the dose received.

A worker was exposed to 5 mR/hr for 45 minutes. What was the dose received from the worker’s exposure?

$$\frac{\underline{\quad}.\underline{\quad}\ \frac{mR}{hr} \times \underline{\quad}.\underline{\ }\ (\text{min})}{60\ \frac{\text{min}}{hr}} = \underline{\quad}.\underline{\quad}\ (\text{mR})$$

Appraisal (Page 6 of 10)

The following example will allow you to practice using the inverse square calculation to determine the distance where an exposure reaches I_2.

If an x-ray source emits 200 mR/hr at 8 ft, where would you expect to measure 4 mR/hr?

After you’ve calculated the distance for where the exposure reaches I_2, select your answer, rounded to a whole number.

A 8 ft

B 57 ft

C 200 ft

D 3,200 ft

Nooneberg AB Scenario (Page 7 of 10)

As you begin preparing your specific recommendations for controls at the NDI shop, you review your notes to ensure proper shielding is being used to protect the radiation workers and education center personnel moving into the adjoining offices.

Scenario Challenge Point (Page 8 of 10)

You know x-rays are highly penetrating and are considered high-energy electromagnetic radiation. You also know composite plastic barriers are currently being installed in the shop's sheetrock. Which one of the following recommendations would be *most* appropriate regarding control of the radiation health threat at the NDI shop?

A The composite plastic barriers will offer sufficient shielding and should continue to be used in remodeling of the shop.

B The composite plastic barriers will offer sufficient shielding; however, the x-rays would be sufficiently controlled by only sheetrock.

C The composite plastic barriers will not offer sufficient shielding alone. Technicians should also use lead aprons and gloves.

D The composite plastic barriers will not offer sufficient shielding. The shielding material should be replaced with lead.

Selecting Shielding Based on Type of Ionizing Radiation (Page 8a of 10)

Each type of radiation has specific qualities which require various degrees and types of shielding. In order for shielding to be effective, the materials used must be appropriate for the type of radiation present.

As always, you should follow the hierarchy of controls when making recommendations. It is also important to note that controls can be used in combination with other controls to **best** protect personnel.

Alpha

Alpha particles are heavy and doubly charged which cause them to lose their energy very quickly in matter. They can be shielded by a sheet of paper or the surface layer of skin. Alpha particles are considered hazardous to a person's health only if an alpha particle is ingested or inhaled.

Beta

Beta particles are much smaller than other types of particulate radiation and have only one charge, which causes them to interact more slowly with material. They are effectively shielded by thin layers of metal or plastic and are considered hazardous only if ingested, inhaled, or exposed to the skin causing beta burns.

For high-energy beta radiation, lead alone is not an appropriate shielding material because of the potential for x-ray production (bremsstrahlung). Ask your RSO for further guidance in these situations.

Gamma and X-rays

Both gamma rays and x-rays are forms of high-energy electromagnetic radiation. X-rays and gamma rays are best shielded by layers of lead or other dense materials and can be extremely hazardous to people.

Neutrons

Neutrons are neutral particles with approximately the same mass as a proton. Because they are neutral, they are highly penetrating and interact only weakly with material. They are an external hazard and best shielded by layers of concrete.

Scenario Challenge Point (Page 9 of 10)

In addition to lead shielding, which two of the following are engineering controls that could be recommended for use in the NDI shop?

A Annual radiation refresher training.

B Restricting access to radiation areas.

C Install access interlock systems.

D Monthly monitoring of exposure limits.

E Visible and audible warning signals.

Lesson Summary (Page 10 of 10)

Radiation, as with any health threat, can be controlled through the use of engineering and administrative controls, as well as PPE. Engineering controls for radiation include shielding, access interlock systems, and visual and audible warning signals. Administrative controls include controlling the time exposed to and the distance from a radiation source, thereby decreasing the dose received. PPE, such as gloves and aprons, should be used as a last resort when other controls aren’t feasible.

In this lesson you:

- Recalled control requirements for ionizing radiation.
- Recalled principles of dose, dose rate, and time related to ionizing radiation.
- Determined appropriate controls for ionizing radiation.
- Recalled appropriate calculations that relate to ionizing radiation.
- Performed appropriate ionizing radiation calculations.

Audio Script

Narrator: After evaluating the planned controls for the shop, you provide recommendations to the shop supervisor based on your observations. Since the plastic barriers being installed are not going to provide adequate protection, you recommend they install lead shielding to protect workers from the x-rays produced in the shop. You also recommend the use of visual and audible warning signals and access interlock systems.

Lesson 5: RAM Storage and Use Survey

Lesson Description

In this lesson, you will be conducting a radioactive materials (RAM) storage and use survey and assisting a technician with performing a shipment and transport survey. Upon completion of this lesson, you will be able to perform a RAM storage and use survey and survey radioactive materials for shipment or transport.

Lesson Overview (Page 1 of 11)

While working on the radioactive materials (RAM) storage and use survey and preparing RAM for transport, you will:

- Determine why and when RAM storage and use surveys are performed.
- Recall steps for performing RAM storage and use surveys.
- Determine why and when RAM is surveyed for shipment or transport.
- Recall steps for surveying RAM for shipment or transport.
- Recall the RAM shipment / transport survey calculation.
- Perform appropriate ionizing radiation calculations.

Audio Script

NCOIC: Good morning! I've been reviewing some work that we need to get done. From the records I have, it looks like the lab on base needs a storage and use survey completed. I'm assigning this task to you for today.

Scenario Challenge Point (Page 2 of 11)

When you arrive at the lab, you begin by identifying the sources of RAM which should be surveyed.

Which two of the following are RAM sources that can be surveyed in a RAM storage and use survey?

A Sealed Sources

B X-ray Sources

C Unsealed Sources

D Radio Frequency Sources

Radioactive Materials in the Air Force (Page 2a of 11)

The Air Force uses **RAM** to perform a variety of missions. RAM can be encountered in nuclear medicine departments when diagnosing or treating diseases, when conducting non-destructive inspections, or as a byproduct of industrial operations, for instance.

Because of the wide variety of sources and uses of RAM in the Air Force, it's important to have a comprehensive program to manage and control radioactive substances from the time they are created to the time they are properly disposed of. The management of radioactive substances is in place to protect workers and the environment from harmful exposures to radiation.

Radioactive Material (RAM)

Radioactive material (RAM) is material which contains unstable (radioactive) atoms that give off radiation as they decay or transform.

Purpose of a RAM Storage and Use Survey (Page 2b of 11)

A RAM storage and use survey is performed on both **sealed** and **unsealed** sources of RAM. It's important to perform these surveys because they ensure that radioactive materials are used and stored in compliance with appropriate standards. Most surveys are conducted at least annually; however, the frequency depends on the type and quantity of RAM.

Sealed Sources of RAM

When radiation is unable to be released into the environment because it is encased or enclosed, it is considered a sealed source of RAM. The purpose of performing a survey on sealed sources of RAM is to ensure that the seal is not compromised.

Examples of sealed sources of RAM include:

- Instrument check sources.
- Instrument calibration equipment.
- Blood irradiators.

Unsealed Sources of RAM

Loose RAM which is not sealed or fixed in a surface is considered an unsealed source of RAM. This type of RAM is used extensively in bio-research and medicine, and may be generated during certain maintenance operations. The purpose of surveying unsealed sources of RAM is to ensure the radioactive materials are not being released into the environment or cross-contaminating other materials.

Examples of unsealed sources of RAM include:

- Medical/diagnostic material/liquids (e.g., Technetium-99m).
- Magnesium-thorium engine parts.
- Thoriated glass in targeting pods.
- Tritium in Exit signs.

Scenario Challenge Point (Page 3 of 11)

Before you begin your survey at the lab, put the tasks you will perform in the correct order. Write the letter corresponding to the appropriate step on each blank.

Word Bank	Order
Take background measurements in the survey area.	1. ________________
Identify all locations where you are taking readings on the diagram.	2. ________________
Compare the annual dose equivalent to the appropriate standard.	3. ________________
Calculate the annual dose equivalent.	4. ________________
Sketch a diagram of the radiation storage area.	5. ________________
Use an ion chamber to determine dose rate exposure measurements.	6. ________________

Steps for Performing a RAM Storage and Use Survey (Page 3a of 11)

Use the following steps to conduct a RAM storage and use survey:

1. Sketch a diagram of the radiation storage area, including all adjacent areas.
2. Take background measurements in the survey area.
3. On the diagram, identify all locations where you are taking readings.
4. Use an ion chamber to determine dose rate exposure measurements. The measurements should be taken 30 cm from external sources or surfaces that the radiation penetrates. If the instrument readings fluctuate significantly, you should use the highest reading. Normally, you should take the average readings.
5. Calculate the annual dose equivalent.
6. Compare the annual dose equivalent to the appropriate annual dose limit standard.

Surveying RAM for Shipment or Transport (Page 4 of 11)

As important as it is to survey RAM in controlled environments such as labs, it's also important to ensure that RAM is shipped and transported safely between controlled environments.

There are numerous federal regulations which establish the guidelines for transporting RAM. If you don't follow the established regulations, not only could you be breaking federal law, but you could also be allowing people to become contaminated or unnecessarily exposed.

Because of stringent federal regulations governing the shipment of RAM, you must attend a Department of Transportation (DOT)/International Air Transport Association (IATA) class and pass applicable tests to be certified to ship radioactive materials.

RAM packages must be surveyed both before and after shipment or transport to ensure that the package is sealed and marked appropriately and not damaged during transport.

Steps for Surveying RAM for Shipment or Transport (Page 5 of 11)

When receiving RAM, gloves should be worn until the package has been surveyed.

The survey should be conducted as soon as possible after receiving a package which contains RAM, and may have to occur no later than 3 hours after the RAM has arrived depending on the type or quantity of material. Your RSO can provide further guidance related to time requirements.

Before beginning the survey, you should inspect the outer package for physical damage. If it is severely damaged, set the package aside and call the RSO.

You should follow a specific set of steps to ensure that the package was not damaged in transit and is safe to open.

Note: RAM packages should contain both outer and inner packaging.

Step 1: Take a dose rate exposure measurement on all sides of the outer package on contact and one meter from each surface.

Step 2: Perform a swipe on the outer package.

Step 3: Verify proper labeling and markings on the package.

Step 4: If package swipes and dose rate measurements are below applicable standards, open the outer package and perform a dose rate measurement four inches from the inner package. Also, perform a swipe on the inside of the package.

Step 5: Record the results.

Appraisal (Page 6 of 11)

You will see several questions to check your knowledge of the steps for surveying RAM for shipment or transport. Select the correct answer for each question.

When must radioactive materials be surveyed for shipment and transport?

A Only before shipment

B Only after shipment

C Before and after shipment

Which one of the following statements is true regarding the shipment and transport of radioactive materials (RAM)?

A Anyone can ship radioactive materials with appropriate packaging and notifications.

B RAM shipments are exclusively overseen by the Nuclear Regulatory Commission (NRC).

C You must attend a special training course and pass a test to be certified to ship RAM.

How far away from the RAM package should you take an initial dose rate measurement when performing a RAM shipment and transport survey?

A 1 inch

B 1 foot

C 1 meter

If the package swipes and dose rate measurements are below applicable standards for receiving a RAM shipment, what should you do next?

A Open the outer package, unwrap the inner package and store the RAM in a locked storage unit.

B Open the outer package and perform a dose rate measurement four inches from the inner package.

C Open the outer package but do not open the inner package around the RAM, and then place it in the storage unit.

Calculating the Disintegrations per Minute (page 7 of 11)

While surveying RAM for shipment and transport, you will calculate the disintegrations per minute (dpm), and then compare the findings to appropriate standards and the RAM permit.

You will use the ADM-300 to survey the swipe filter of the package, which will give you the counts per minute (cpm) detected. In addition to taking into account the net cpm, you will also use the counting efficiency of the survey instrument to calculate the dpm.

Use the following formula for your calculation:

$$dpm = \frac{net\_cpm}{counting\_efficiency}$$

Determining the Safety of the Package (page 8 of 11)

Once you have calculated the dpm, you will determine if your package is safe for shipment. A package is considered safe for shipment if the dpm does not exceed the applicable standard for the type of RAM being shipped.

When you swipe a package, you normally swipe a 300 cm^2 area, but sometimes the total surface area may be less than that. Remember to record the actual area you swipe so you can use it later in your calculations.

Use the following formula to determine the dpm/cm^2:

$$\frac{dpm}{(swipe\_area)cm^2} = dpm/cm^2$$

Scenario Challenge Point (page 9 of 11)

While you're at the lab conducting the storage and use survey, one of the new technicians asks you to help him complete a shipment and transport calculation for a package he is attempting to ship. Using the information provided, calculate the disintegrations per minute (dpm) for the package.

- Net cpm: 200
- Counting efficiency: 50%

A 400 dpm

B 200 dpm

C 100 dpm

D 40 dpm

Scenario Challenge Point (page 10 of 11)

The next step you help the technician with is determining if the package is safe for shipment.

Given the dpm for the package is 400 dpm and the area swiped is 300 cm2, is the package within a standard of 22 dpm/cm2 for shipment or transport?

$$\frac{dpm}{(swipe\_area)cm^2} = dpm/cm^2$$

A Yes

B No

Lesson Summary (page 11 of 11)

Because of the wide variety of sources and uses of RAM in the Air Force, it's important to have a comprehensive program to manage and control radioactive substances from the time they are created to the time they are properly disposed of.

The RAM storage and use survey is one method for monitoring these materials. This survey is used to ensure the safety of personnel and the general public.

In addition to monitoring the storage and use of RAM, it's also important to survey RAM packages before and after transport or shipment to ensure the packages are safe and all transportation laws are followed.

In this lesson, you:

- Determined why and when RAM storage and use surveys are performed.
- Recalled steps for performing RAM storage and use surveys.
- Determined why and when RAM is surveyed for shipment or transport.
- Recalled steps for surveying RAM for shipment or transport.
- Recalled the RAM shipment / transport survey calculation.
- Performed appropriate ionizing radiation calculations.

Audio Script

Narrator: While you completed the task of performing a storage and use survey at the lab on base, you also assisted a new technician with completing a shipment and transport calculation for a RAM package being prepared for shipment. The package was securely shipped after approval from the OIC.

When you return to the BE shop and review your notes, you determine the exposure to RAM is within acceptable limits. Therefore, no recommendations for corrective actions were needed.

Lesson 6: Disposal of Radioactive Materials

Lesson Description

In this lesson, you will review materials from a training course about properly disposing of radioactive materials in the Air Force. Upon completion of this lesson, you will be able to describe the considerations for disposal of radioactive waste in conjunction with the Air Force Radiation and Radioactive Recycling and Disposal (AFRRAD) office.

Lesson Overview (Page 1 of 5)

The Air Force uses many different types of radioactive materials which must be disposed of properly after their intended use. The Air Force Radiation and Radioactive Recycling and Disposal (AFRRAD) office at Wright-Patterson AFB (WPAFB) is the central point of contact for all questions related to radioactive and mixed waste from Air Force operations.

While reviewing the training course materials about disposing of radioactive waste, you will:

- Describe the methods for disposal of radioactive material.
- Recall the role of the Air Force Radiation and Radioactive Recycling and Disposal (AFRRAD) office in radioactive materials disposal.

Audio Script

AFRRAD Office Worker: AFRRAD office.

BE Tech: Hello. I'm a technician with Bioenvironmental Engineering. There's a small amount of radioactive waste in the shop and I've been placed in charge of disposing of it. Do you have any information you could send me about proper disposal procedures?

AFRRAD Office Worker: Sure. I'll send you some slides and handouts from a course we offer on-site. The information covers the options available for radioactive waste disposal.

BE Tech: That'd be great. Thank you!

Methods for Disposal of Radioactive Materials (Page 2 of 5)

When disposing of **radioactive materials** that are no longer needed, there are several options to consider. All methods require the RAM to be inventoried and secured until the disposal or transfer can occur.

The disposal or transfer should occur as soon as practical, and the collection or storage of the RAM should not exceed one year. Mixed waste shall not be stored for longer than 90 calendar days unless an issued Resource Conservation Recovery Act (RCRA) permit authorizes storage for up to the 365 day limit.

Disposal of RAM also includes proper removal and disposal of various nuclear wastes.

There are three preferred methods of RAM disposal in the Air Force.

- **Return to manufacturer.**
- **Transfer to another user.**
- **Recycle.**

Radioactive Materials

Examples of typical sources of radioactive materials in the Air Force include:

- Compasses or aircraft instruments containing radium.
- Lenses which contain thorium.
- Aileron counterweights made from depleted uranium.
- Magnesium-thorium alloys used in aircraft parts.
- Electron tubes which contain various isotopes.
- Radiopharmaceuticals.
- Instrument radioactive check sources.

Return to Manufacturer

The preferred method for disposing of radioactive waste is to return it to the manufacturer after use. Returning the RAM to the manufacturer is usually the cheapest way to dispose of the RAM properly because most manufacturers already include the cost of returning it to them in the purchase price.

Transfer to Another User

There may be other areas of the Air Force which can benefit from certain types of radioactive materials when no longer in use. If this option is available, you should make arrangements to transfer the RAM to the possession of another user within the Air Force. For example, radioactive check sources that are no longer needed at one base can be sent to another base.

Most transfers should be coordinated through the AFRRAD office because they have information about who needs the RAM or who is willing to accept it.

Recycle

Recycling the radioactive waste allows the waste to be properly disposed of and used for other purposes both by the Air Force and the private sector.

For example, depleted uranium from counterweights of aircraft could be recycled and used in tank armor. The AFRRAD office determines if and how the material can be recycled.

Radioactive and Mixed Waste Disposal (Page 3 of 5)

If you have exhausted preferred options, the AFRRAD office will assist with disposal. The AFRRAD office's primary function is to coordinate the shipment and disposal of waste in compliance with the Environmental Protection Agency (EPA) and Nuclear Regulatory Commission (NRC) regulations.

You must provide certain **required information** to the AFRRAD office when using their disposal services.

Required Information

When requesting disposal of radioactive materials, you will need to provide the following information:

- Nomenclature and/or description.
- National Stock Number (NSN).
- Quantity of each item.
- Radionuclide(s).
- Proper shipping name and UN number.
- Chemical and physical form.
- Activity of commodity

Appraisal (Page 4 of 5)

While reviewing the materials sent by the AFRRAD office, you see several questions used during the on-site course to review the students' knowledge about disposing of RAM.

Check your own knowledge about disposing of radioactive and mixed waste in the Air Force by answering each question.

Which one of the following methods is considered the most desirable option when disposing of radioactive materials?

A Recycle

B Disposal through the AFRRAD office

C Return it to manufacturer

D Transfer it to another user

Which one of the following methods is considered the least desirable option when disposing of radioactive materials?

A Disposal through the AFRRAD office

B Transfer it to another user

C Return it to manufacturer

D Recycle

Which of the following is the central point of contact for the disposal of radioactive materials for the Air Force?

A USAFSAM

B AFRRAD office

C AFMOA

D NRC

Which two of the following pieces of information are required when requesting disposal of radioactive materials?

A Transfer history of RAM

B Method of shipment

C Chemical and physical form

D Activity of commodity

Lesson Summary (Page 5 of 5)

The three preferred methods for disposing of radioactive materials and mixed waste are to return it to the manufacturer, transfer it to another user, or recycle. If it is not feasible to use any of these three methods, the Air Force Radiation and Radioactive Recycling and Disposal (AFRRAD) office will assist with proper disposal.

In this lesson you:

- Described the methods for disposal of radioactive material.
- Recalled the role of the Air Force Radiation and Radioactive Recycling and Disposal (AFRRAD) office in radioactive materials disposal.

Audio Script

Narrator: You and your OIC review all disposal options and determine the best course of action is to contact the Air Force Radiation and Radioactive Recycling and Disposal office to arrange for proper disposal. After providing the required information, arrangements were made to properly dispose of the waste

Resources

- AFT 48-148, Ionizing Radiation Protection
- AFMAN 48-125,Personnel Ionizing Radiation Dosimetry
- Bioenvironmental Engineer's Guide to Ionizing Radiation, 2005
- TO 33B-1-1, Nondestructive Inspection Methods, Basis Theory
- AFI 40-201, Managing Radioactive Materials in the US Air Force
- AFSC FORM 3587
- 49 CFR 172.402
- 49 CFR 172.436-440
- 49 CFR 173.403
- NRC Regulations Title 10, CFR 20
- Electronic Code of Federal Regulations
- NRC Regulations

Answer Key: Appraisals / Scenario Challenge Points

Lesson 1: Fundamentals and Effects of Ionizing Radiation

Page 2 of 8

You will see several incomplete statements associated with ionizing radiation. Use the word bank to fill in the blanks that correctly complete the statement. Terms can be used more than once.

An element with the same number of protons, but different number of neutrons is known as a(n) __**Isotope**__.

This electron displacement, called ___**Ionization**___ creates two electrically charged particles which may cause changes in living cells, plants, animals, and people.

Energy in the form of waves or moving subatomic particles emitted by an atom or other body as it changes from a higher energy state to a lower energy state is known as __**Radiation**__.

___**Radioactive Decay**___ is the spontaneous disintegration or transformation of an atom in an attempt by that atom to reach a stable state.

A(n) __**Radioisotope**__ is an unstable __**Isotope**__ that, in an attempt to become a stable atom, emits energy in the form of __**Radiation**__.

__**Linear Energy Transfer**__ is energy lost by particles along the path through which they are traveling.

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Match each type of ionizing radiation to the description of how it interacts with matter.

Types of Ionizing Radiation	**Description**
Alpha	Can interact through ionization or excitation
Gamma and X-ray	Can react through the photoelectric effect, Compton scatter, and pair production.
Beta	Can interact through ionization or bremsstrahlung.
Neutron	Is the most penetrating of these types or radiation.

Rationale: Alpha particles can interact with matter through ionization or excitation. Beta particles can interact with matter through ionization and bremsstrahlung. Gamma and x-rays interact with matter through the photoelectric effect, Compton scatter, and pair production. Neutrons are less common than other forms of ionizing radiation but are the most penetrating type of radiation.

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Match each statement with the biological effects of ionizing radiation by marking the appropriate blocks in the table.

Description	Indirect Effects	Direct Effects	Acute Effects	Chronic Effects	Deterministic Effects	Stochastic Effects
Occur at the physical point of exposure and can immediately cause damage to any molecule.		X				
A certain minimum dose must be exceeded before the particular effect is observed.					X	
Often occur due to occupational exposures to many small doses over a period of 20 to 30 years or more.				X		
The probability of the effect increases with an increase in dose.						X
Have both immediate and long-term effects since permanent damage has likely been caused.			X			
Occurs when cell damage is sustained from by-products of the exposure.	X					

Rationale: Indirect effects occur when cell damage is sustained from by-products of the exposure. Direct effects occur at the physical point of exposure and can immediately cause damage to any molecule. Acute effects have both immediate and long-term effects since permanent damage has likely been caused. Chronic effects often occur due to occupational exposures to many small doses over a period of 20 to 30 years or more. Deterministic effects require a certain minimum dose must be exceeded before the particular effect is observed. Stochastic effects are those effects that occur by chance among unexposed as well as exposed individuals and the only relationship between the dose and the effects is that the probability of the effect increases with an increase in dose.

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Place the types of radiation in order of *lowest* dose in REM to the *highest* dose in REM.

Word Bank	**List**	
Neutrons	**Gamma / X-Rays**	Lowest Dose in REM
Gamma / X-Rays	**Beta particle**	⇓
Alpha particle	**Neutrons**	
Beta particle	**Alpha particle**	Highest Dose in REM

Rationale: Gamma / x-rays and beta particles have the lowest dose in REM, followed by neutrons of unknown energy. Alpha particles have the highest dose in REM.

Lesson 2: Scatter Surveys

Page 3 of 10

Which two of the following are methods through which x-rays can be produced?

C Characteristic

D Bremsstrahlung

Rationale: X-rays can be produced through the Bremsstrahlung and characteristic methods. Bremsstrahlung x-rays are produced when high-speed electrons interact with a positive nucleus, causing a change in speed and direction. Characteristic x-rays are produced when electrons backfill other electrons when they have been ejected from an atom. The result is a loss of kinetic energy in the form of an x-ray. Excitation occurs when there is an addition of energy to an atomic system, changing the atom from a ground state to an excited state. Nuclear stability describes an atom having a n:p ratio that is considered stable for that element.

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While SrA Jones goes to the truck to get the necessary survey equipment, Mr. Kim asks you why it’s necessary to call BE any time a new piece of x-ray equipment is moved or purchased. You take the opportunity to explain the importance of ensuring not only the safety of the patients, but also of the personnel working around the equipment. Build a list of situations that would require a medical / diagnostic x-ray scatter survey to be performed.

List
Shielding changes have occurred.
A new x-ray unit was installed in the building.
A new office was places next to an exposure room.

Rationale: BE should conduct medical / diagnostic x-ray scatter surveys upon initial acceptance of an x-ray unit, when conducting a baseline survey, for the mandatory annual survey to ensure nothing has changed with the operation of the equipment, and any time modifications or changes in operation have occurred.

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Select the locations where you plan to collect measurements.

	Hallway		Unoccupied Storage
X	Door		Cassette Holder
X	Developing Room	**X**	Facility Management Office
X	Film Pass Through	**X**	Waiting Area 1
X	Console	**X**	Waiting Area 2
	Table		

Rationale: You should collect measurements at the console, in the hallway at the door, the developing room, the film pass through, the facility management office, and both waiting areas. Based on the current layout and use of space, you do not need to take measurements from the table, in front of the cassette holder, in the hallway, or in the unoccupied storage area.

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Which one of the following steps should be completed immediately before Mr. Kim turns on the x-ray?

B Place a 1-gallon container of water in the beam or its equivalent.

Rationale: After you have sketched the area and labeled the measurement locations, you should have the x-ray technician set up the unit using the maximum and normal settings and the appropriate field for the type of x-ray configuration. Next, place a 1-gallon container of water in the beam or its equivalent and set up your meter. Once these steps have been completed, the x-ray may be turned on.

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What is the annual exposure for non-radiation personnel occupying the facility management office adjacent to the x-ray room?

Use an Occupancy Factor of 1 and round to the nearest whole number.

B 16 mR

Rationale: The annual exposure for non-radiation personnel occupying the facility management office is 16 mR. The annual exposure for this situation is calculated by first multiplying the scatter survey result at the facility management office (2.5 μR) by the number of films taken at the MTF per year (27,375). Then, to convert the units to mR, you divide that number by 1,000 μR. Next, multiply that number times the percentage of the year a worker will be exposed (0.228). Multiplying that result times an occupancy factor of 1, gives you the annual exposure for personnel occupying the facility management office.

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You determined that non-radiation personnel occupying the facility management office receive an annual exposure of 16 mR.

Using the accepted exposure standard of 100 mR/yr for non-radiation workers in the MTF, does the annual exposure received represent a concern that requires further action?

B No

Rationale: Since the annual exposure for the non-radiation workers in the MTF does not exceed the accepted standard, it is not a cause for concern and requires no further action at this time.

If the annual exposure for the non-radiation workers *did* exceed the accepted standard, it would be a cause for concern. Which two of the following could you recommend as a next course of action in that instance?

A Relocate or rearrange the workspace of the non-radiation workers.

D Relocate the cassette holder to an unoccupied storage wall and re-measure.

Rationale: If the dose estimation determined using the Medical / Industrial X-Ray Survey Calculation, *did exceed* the annual exposure for the non-radiation workers in the MTF, you could recommend relocating or rearranging the workspace of non-radiation workers or relocating the cassette holder to the wall adjacent to an unoccupied storage area and then re-measuring. Issuing PPE to all non-radiation workers or suspending all x-ray operations at the MTF would cause undue hardship on the mission and would not viable options.

Before recommending controls, the BEE/Radiation Safety Officer (RSO) may utilize other methods, such as placing a dosimeter near personnel for a given amount of time, to confirm the actual dose of radiation being received.

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Even though the dose being received by non-radiation personnel at the MTF is not above the accepted exposure standard, you decide to review your notes to determine whether personnel are receiving the lowest level of radiation possible from the x-ray machine.

The "As Low As Reasonably Achievable" (ALARA) concept is used to minimize the effects of radiation exposure even when exposure is below the occupational exposure limit. Which two of the following are examples of utilizing the ALARA concept?

A Establishing workplace action limits

D Posting warning signs

Rationale: The ALARA concept should be used when designing or modifying work areas, including determination of the appropriate material and thickness for shielding. BE uses this concept to ensure adequate radiation safety is incorporated into the design plan of new facilities. Examples of using the ALARA concept include: establishing workplace or process specific action limits, controlling access to the exposure room, posting warning signs, providing annual training, and performing proper maintenance of the x-ray unit.

Lesson 3: Performing an Ionizing Radiation Overexposure Investigation

Page 2 of 7

Which two of the following situations would prompt an overexposure investigation?

B	**A radiographic supervisor suspects someone has been overexposed in the shop.**
E	**An individual's thermoluminescent dosimeter (TLD) results are greater than 500 mR.**

Rationale: suspected overexposure investigation will occur when an individual's TLD results are greater than 500 mR, an individual's EPD in NDI situations alarms above 500 mR, a radiographic supervisor suspects someone has been overexposed, or a survey meter is returned with readings over the overexposure limit.

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Build a list of the information you should be able to determine based on your data collection of the incident.

List
The portion of the individual's body exposed.
The circumstances surrounding the abnormal exposure.
The validity of the dose received.
Any corrective actions required to prevent a recurrence.

Rationale: The data collected about the potential overexposure is used to determine the circumstances surrounding the abnormal exposure, the validity of the dose received, the portion of the body exposed, and any corrective actions required to prevent a recurrence. While the type of work being performed at the shop, the number of people who have come in contact with the individual, and any controls that are currently in place and operating properly may be needed for some aspect of the investigation, they are not the primary concerns when performing an overexposure investigation.

Page 6 of 7

How long from the time of the overexposure incident do you have to submit the investigation report?

B 7 days

Since you are working with an NDI overexposure incident, to which two of the following offices should you send copies of the incident report?

A USAFSAM

B Air Force NDI Office

Lesson 4: Ionizing Radiation Threat Control Options

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As you continue your inspection, you consider the most appropriate methods for controlling radiation health threats in the NDI shop.

Match each control with its appropriate description by marking the appropriate blocks in the table.

Description	Distance	Shielding	Time
The first method that should be used to control exposures.			X
Usually the easiest control method to apply.	X		
Provides a physical barrier to absorb radiation energy.		X	

Rationale: Shielding is perhaps the most important method of controlling radiation because it provides a physical barrier to absorb the radiation energy. Time is the first method that should be used to control exposures. Distance is a very effective control method and is usually the easiest to apply.

Page 5 of 10

Use the following example to practice calculating the dose received.

A worker was exposed to 5 mR/hr for 45 minutes. What was the dose received from the worker's exposure?

$$\frac{\mathbf{5}\ \frac{mR}{hr} \times \mathbf{45}\ (\text{min})}{60\ \frac{\text{min}}{hr}} = \mathbf{3.75}(\text{mR})$$

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The following example will allow you to practice using the inverse square calculation to determine the distance where an exposure reaches I_2.

If an x-ray source emits 200 mR/hr at 8 ft, where would you expect to measure 4 mR/hr?

After you've calculated the distance for where the exposure reaches I_2, select your answer, rounded to a whole number.

B 57 ft

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You know x-rays are highly penetrating and are considered high-energy electromagnetic radiation. You also know composite plastic barriers are currently being installed in the shop's sheetrock. Which one of the following recommendations would be *most* appropriate regarding control of the radiation health threat at the NDI shop?

D The composite plastic barriers will not offer sufficient shielding. The shielding material should be replaced with lead.

Rationale: X-rays and gamma rays are best shielded by layers of lead or other dense materials.

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In addition to lead shielding, which two of the following are engineering controls that could be recommended for use in the NDI shop?

C Install access interlock systems.

E Visible and audible warning signals.

Rationale: Other types of engineering controls for radiation exposures that could be recommended include installing visible and audible warning signals and implementing an access interlock system that interrupts the power to the x-ray console if the interlock is broken. While annual radiation refresher training, restricting access to radiation areas, and monthly monitoring of exposure limits may be appropriate to recommend, they are examples of administrative controls. It is important to recognize that various methods of controls can be used together to protect personnel from radiation overexposures.

Lesson 5: RAM Storage and Use Survey

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When you arrive at the lab, you begin by identifying the sources of RAM which should be surveyed. Which two of the following are RAM sources that can be surveyed in a RAM storage and use survey?

A Sealed Sources

C Unsealed Sources

Rationale: A RAM storage and use survey is performed on both sealed and unsealed sources of RAM. X-rays are typically surveyed using a scatter survey, which is not an accepted method for surveying RAM. In Air Force operations, x-rays are usually machine-produced. Radio frequency radiation is typically surveyed using an RFR measurement survey.

Page 3 of 11

Before you begin your survey at the lab, put the tasks you will perform in the correct order.

1. **Sketch a diagram of the radiation storage area.**
2. **Take background measurements in the survey area.**
3. **Identify all locations where you are taking readings on the diagram.**
4. **Use an ion chamber to determine dose rate exposure measurements.**
5. **Calculate the annual dose equivalent**
6. **Compare the annual dose equivalent to the appropriate standard.**

Rationale: In order to perform a RAM storage and use survey you should first sketch a diagram of the radiation storage area, including all adjacent areas, then take background measurements in the survey area. On the diagram, identify all locations where you are taking readings. Then, use an ion chamber to determine dose rate exposure measurements and calculate the annual dose equivalent. Finally, you should compare the annual dose equivalent to the appropriate annual dose limit standard.

Page 6 of 11

When must radioactive materials be surveyed for shipment and transport?

C Before and after shipment

Which one of the following statements is true regarding the shipment and transport of radioactive materials (RAM)?

C You must attend a special training course and pass a test to be certified to ship RAM.

How far away from the RAM package should you take an initial dose rate measurement when performing a RAM shipment and transport survey?

C 1 meter

If the package swipes and dose rate measurements are below applicable standards for receiving a RAM shipment, what should you do next?

B Open the outer package and perform a dose rate measurement four inches from the inner package.

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While you're at the lab conducting the storage and use survey, one of the new technicians asks you to help him complete a shipment and transport calculation for a package he is attempting to ship. Using the information provided, calculate the disintegrations per minute (dpm) for the package.

- Net cpm: 200
- Counting efficiency: 50%

A 400 dpm

Rationale: Remember to use the following equation:

$$dpm = \frac{net\_cpm}{counting\_efficiency}$$

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The next step you help the technician with is determining if the package is safe for shipment.

Given the dpm for the package is 400 dpm and the area swiped is 300 cm2, is the package within a standard of 22 dpm/cm2 for shipment or transport?

$$\frac{dpm}{(swipe\_area)cm^2} = dpm/cm^2$$

A Yes

Rationale: The calculated dpm/cm2 for the package is 1.33 dpm/cm2, which is less than the given standard of 22dpm/cm2 for shipment or transport. Therefore, the package is within the permissible limits.

Lesson 6: Disposal of Radioactive Materials

Page 4 of 5

Which one of the following methods is considered the most desirable option when disposing of radioactive materials?

C Return it to manufacturer

Which one of the following methods is considered the least desirable option when disposing of radioactive materials?

A Disposal through the AFRRAD office

Which of the following is the central point of contact for the disposal of radioactive materials for the Air Force?

B AFRRAD office

Which two of the following pieces of information are required when requesting disposal of radioactive materials?

C Chemical and physical form

D Activity of commodity

Course Glossary

Acronyms

AAR
After Action Report

ACADA
Automatic Chemical Agent Detection Alarm

AFI
Air Force Instruction

AFMIC
Armed Forces Medical Intelligence Center

AFMS
Air Force Medical Service

AFMSA
Air Force Medical Support Agency

AFOSH
Air Force Occupational and Environmental Safety, Fire Prevention and Health

AFRRAD
Air Force Radiation and Radioactive Recycling and Disposal

ALARA
As Low As Reasonably Achievable

AMC
Aerospace Medicine Council

amu
Atomic Mass Unit

AO
Area of Operations

AOC
Area of Concern

AOR
Area of Responsibility

BE
Bioenvironmental Engineering Flight

CBRN
Chemical, Biological, Radiological, Nuclear

CE
Civil Engineering

COA
Course of Action

COC
Contaminant of Concern or Constituent of Concern

CONUS
Continental United States

CSM
Conceptual Site Model

CV
Coefficient of Variability

DIA
Defense Intelligence Agency

DF
Duty Factor

DOD
Department of Defense

DOE
Department of Energy

DOS
Department of State

DOT
Department of Transportation

D_{pel}
Estimated Hazard Distance

DRI
Direct Reading Instruments

EHF
Extremely High Frequency (Occurs between 30 and 300 GHz)

EMR
Electromagnetic Radiation

EPA
Environmental Protection Agency

EPD
Electronic Personal Dosimeters

FPWG
Force Protection Working Group

G_{abs}
Absolute Gain

HF
High Frequency (Occurs between 3 and 30 MHz)

HRA
Health Risk Assessment

HRE
Health Risk Estimate

HRM
Health Risk Management

IATA
International Air Transport Association

IPE
Individual Protection Equipment

LCL
Lower Confidence Limits

LET
Linear Energy Transfer

LF
Low Frequency (Occurs between 30 and 300 kHz)

MAJCOM
Major Command

MEDIC CD
Medical Environmental Disease Intelligence and Countermeasure CD

MIO
Medical Intelligence Officer

MF
Medium Frequency (Occurs between 300 and 3,000 kHz (3MHz))

MOPP
Mission Oriented Protection Posture

MPE
Maximum Permissible Exposure

MSP
Mission Support Plan

NFB
Near-Field Boundary

NGIC
National Ground Intelligence Center

NHZ
Nominal Hazard Zone

NIOSH
National Institute for Occupational Safety and Health

NOHD
Nominal Ocular Hazard Distance

NRC
Nuclear Regulatory Commission

OCONUS
Outside the Continental United States

OEH
Occupational and Environmental Health

OEHSA
Occupational and Environmental Health Site Assessment

OEL
Occupational Exposure Limits

OEL-C
Occupational Exposure Limits-Ceiling

OEL-STEL
Occupational Exposure Limits-Short Term Exposure Limit

OEL-TWA
Occupational Exposure Limits-Time Weighted Average

OH
Occupational Health

ORM
Operational Risk Management

OSHA
Occupational Safety and Health Administration

OSI
Office of Special Investigation

P_{avg}
Average Power

PEL
Permissible Exposure Limit

PH
Public Health

P_p
Peak Power

PPBS
Planning, Programming and Budgeting System

PPE
Personal Protective Equipment

PPM
Parts per million

PRF
Pulse Repetition Frequency

PW
Pulse Width

RFR
Radio Frequency Radiation

RSO
Radiation Safety Officer

S
Main-Beam Power Density

SAR
Specific Absorption Rate

S_{avg}
Power Density Average

SEG
Similar Exposure Group

SHF
Super High Frequency (Occurs between 3 and 30 GHz)

SLM
Sound Level Meter

S_{max}
Maximum Power Density

SPL
Sound Pressure Level

TLD
Thermoluminescent Dosimeters

TWG
Threat Working Group

UHF
Ultra High Frequency (Occurs between 300 and 3,000 MHz)

USACHPPM
United States Army Center for Health Promotion and Preventive Medicine

UTC
Unit Type Code

VA
Vulnerability Assessments

VHF
Very High Frequency (Occurs between 30 and 300 MHz)

VLF
Very Low Frequency (Occurs between 3 and 30 kHz)

Definitions

Absolute Gain (G_{abs})
The ratio of the power that would be required at the input of an ideal isotropic radiator to the power actually supplied to the given antenna, to produce the same radiant intensity in the far-field region.

Action Level
An airborne exposure level that dictates active air monitoring, medical monitoring, and employee training. The Action Level is one-half the Occupational Exposure Limit for time-weighted average (OEL-TWA) exposures, except where 29 CFR 1910 Subpart Z designates a different concentration or where the statistical variability of sample results indicates that a lower fraction of the OEL should be used as the Action Level.

Activity
The number of disintegrations or transformations of radioactive material per unit of time (usually expressed in seconds).

Antenna
The point on an RFR emitter where RFR energy radiates into free space.

Asbestos
A natural material that is made of tiny threads or fibers. The fibers can enter the lungs as a person breathes. Asbestos can cause many diseases, including cancer. Asbestos was used to insulate houses from heat and cold. It has also been used in car brakes and for other purposes. Some old houses still have asbestos in their walls or ceilings.

Asbestosis
A lung disease caused by breathing asbestos fibers over a period of time. The fibers eventually scar the lungs and make breathing difficult. Symptoms are similar to asthma.

Atomic Mass Unit (amu)
Approximately equal to the mass of a proton or a neutron and is used to describe the mass of an atom.

Becquerel (Bq)
The international standard for the unit of measurement for activity.

Breathing Zone
The location where exposure is measured in air sampling. The breathing zone is located forward of the shoulders within 9 inches of the nose and mouth. Breathing zone measurements are taken beneath a welder's helmet or face piece but outside of any respiratory protective devices.

Bremsstrahlung
An interaction that causes a form of x-ray production in which high-speed beta particles penetrate the electron cloud and interact with the nucleus.

Carcinogens
Hazardous materials that stimulate the formation of cancer.

Ceiling Limit (OEL-C)
The limit for an employee's exposure which shall not be exceeded during any part of the work day. If instantaneous monitoring is not feasible, the OEL-C will be evaluated during the worst-case 15-minute exposure period.

Chrysotile
The most common asbestos type. Chrysotile asbestos fibrils may appear crinkled, like permed or damaged hair, under plane-polarized light.

Coefficient of Variation (CV)
For an air sampling method, the CV is the standard deviation of the sampling and analytical error divided by the mean of the sample results. The CV is used to calculate the confidence limits for sampling. OSHA uses the term sampling and analytical error (SAE) to account for the total variation or error in the method.

Compton Scatter
A gamma/x-ray interaction which takes place between a photon and an outer electron where the photon has more energy than the electron can accept, so it imparts only a portion of its energy to the electron.

Conceptual Site Model (CSM)
Articulates the health threats and exposure pathways and begins when data or information is gathered during Predeployment and Baseline Activities.

Confidence Limits
The upper confidence limit (UCL) and lower confidence limit (LCL) are the boundaries for a single sample or a series of samples that have a specified probability (usually 95 percent) of including the true value of the level of exposure.

Controlled Environments
An area where personnel are aware of the potential for RFR exposures associated with their employment or duties.

Counts per minute (cpm)
The amount of radiation detected by an instrument each minute.

Diffuse Reflection
Situations where a laser beam is bounced off a dull or uneven surface that breaks the beam apart.

Disintegration per minute (dpm)
The number of atoms that decay or transform in a given amount of material per minute.

Disintegration per second (dps)
The number of atoms that decay or transform in a given amount of material per second.

Dose
The quantity of radiation absorbed.

Dose Rate
The quantity of radiation absorbed per unit of time.

Duty Factor (DF)
A unit-less number which only applies to pulsed wave systems that describes the ratio of time an RFR emitter is on to the total operating time.

Electromagnetic Radiation (EMR)
Waves of energy that can travel through space and matter.

Electromagnetic Spectrum
The entire frequency range of electromagnetic waves, or wave radiation.

Energy
The ability to do work.

Estimated Hazard Distance (D_{pel})
The distance from the antenna to the point where the power density equals the permissible exposure limit (PEL).

Excitation
Occurs when there is an addition of energy to an atomic system, changing the atom from a "ground" state to an excited state.

Exposure
Exposure occurs when an employee is subjected to a hazardous material through any of these routes: inhalation, ingestion, skin contact, or skin absorption. Airborne exposures are specified as the duration and concentration of hazardous materials measured in the breathing zone of an individual worker without regard for personal protective equipment used by the worker.

Exposure Assessment
An exposure assessment is a process of estimating or calculating potential exposure of a health threat for an individual or population at risk. The assessment includes professional judgment, calculations based on estimates or models, actual measurements, collection and analysis of samples, and statistical evaluation.

Exposure Pathway
Includes a threat and the opportunity for the population to come into contact with the threat.

f
Algebraic express that means, "a function of."

Fission
The splitting of the nucleus of an atom into nuclei of lighter atoms, accompanied by the release of energy.

Frequency
A value of how often a wavelength cycle occurs in a second.

Gain
The antenna's ability to concentrate its energy in a certain direction.

Hazardous materials
Materials that pose a hazard and require a Material Safety Data Sheet as defined in FED-STD 313, Federal Standard, Material Safety Data, Transportation Data and Disposal Data for Hazardous Materials Furnished to Governmental Activities.

Health Risk
The health risk equals threat "combined with" vulnerability (health risk = (threat) + (vulnerability)). A health risk is an identified health threat and the vulnerability of the population at risk of coming into contact (i.e., completion of an exposure pathway) with the health threat.

Health Risk Assessment (HRA)
Health risk assessment is the process of identifying and analyzing or evaluating (exposure and toxicity assessments) OEH threats in populations or at locations over time (HRA = f [(health risk) "+" (HRE) "+" (COA)]). The HRA "product" is the validated health threat, qualified by the HRE, and the COA which includes overall mission impact, recommended control options, associated uncertainties, risk mitigation estimate(s), and a cost-benefit analysis if applicable.

Health Risk Communication
Health risk communication is the process of effectively communicating potential health effects, outcomes, and control measures to all stakeholders (i.e., commanders, supervisors, AF personnel, military, families, and the public). It provides detailed information about the HRA and should occur throughout the HRA process.

Health Risk Estimate (HRE)
Health Risk Estimate is the probability and severity of loss from exposure to the health threat. The HRE is a function of probability and severity when either or both increase the Health Risk Estimate increases. The HRE is also referred to as a health risk level.

Health Risk Management (HRM)
Health risk management is a decision-making process to evaluate and select COAs, minimize OEH risks, and maximize benefits for operations and missions. HRM is the health component of the ORM process and health risk management recommendations and decisions are integrated into the commander's ORM decision-making.

Health Threat
A health threat is a potential or actual condition that can cause short or long-term injury, illness, or death to personnel. A health threat can be occupational or environmental in origin; internal or external to the installation; or continuous, intermittent, or transient; and includes enemy capability and intent.

Ionization
Occurs when beta particles interact with nearby atoms causing an electron to be removed, creating an ion pair.

Ionizing Radiation
Radiation which has enough energy to change the atomic structure of matter.

Isotope
Elements with the same number of protons, but a different number of neutrons.

Kinetic Energy
Energy of motion.

Laser
Light amplification by stimulated emission of radiation.

Linear Energy Transfer (LET)
Energy lost by particles along the path through which they are traveling.

Mass
Description of how much matter there is present in an object.

Maximum Permissible Exposure (MPE)
The level of laser radiation to which a person may be exposed without hazardous effects or adverse biological changes in the eyes or skin.

Mesothelioma
Cancer that generally occurs in the chest, abdominal region, and areas surrounding the heart. It is typically associated with exposure to asbestos.

n
Algebraic express that means, "Number of samples."

Nominal Hazard Zone (NHZ)
The area within a laser workplace in which the exposure from direct beam, specular reflection, and diffuse reflection could exceed the Maximum Permissible Exposure (MPE).

Nominal Ocular Hazard Distance (NOHD)
The distance along the laser beam beyond which the exposure is not expected to exceed the appropriate Maximum Permissible Exposure (MPE).

Non-aqueous Phase Liquids (NAPLs)
Non-aqueous phase liquids are liquids that are sparingly soluble in water. Because they do not mix with water, they form a separate phase. For example, oil is an NAPL because it does not mix with water, and oil and water in a glass will separate into two separate phases. NAPLs can be lighter than water (LNAPL) or denser than water (DNAPL). Hydrocarbons, such as oil and gasoline, and chlorinated solvents, such as trichloroethylene, are examples of NAPLs.

Non-ionizing Radiation
Radiation which does not have enough energy to change the atomic structure of matter.

Nuclear Stability
Describes the certain combinations of neutrons and protons within a nucleus of an atom which are required for that atom to be considered stable.

Occupational and Environmental Health Site Assessment (OEHSA)
The key operational health tool for producing data or information used for health risk assessments (HRA) and to satisfy Occupational and Environmental Health (OEH) surveillance requirements.

Occupational Exposure Limit (OEL)
The limit for the airborne concentrations of a specified substance for a specified time. Employees will not be exposed to concentrations greater than the OEL. The term OEL includes all OEL-TWAs, OEL-STELs, OEL-Cs, and acceptable ceiling concentrations, that apply to a specific substance. For each hazardous material, the OELs are the most stringent limits found in the latest edition of the TLV Booklet published annually by the American Conference of Government Industrial Hygienists, in 29 CFR 1910 Subpart Z, and in AFOSH Standards for specific substances. OELs apply to occupational exposures for each individual worker for a single 8-hour work shift except where 29 CFR 1910 Subpart Z allows 40-hour averages. Exposure during work shifts that exceed 8 hours must be adjusted before applying an OEL.

Operational Risk Management (ORM)
A systematic process of identifying hazards, assessing risk, analyzing risk control options and measures, making control decisions, implementing control decisions, accepting residual risks, and supervising/reviewing the activity for effectiveness.

Optical Cavity
The component that houses the laser.

Pair Production
Occurs when a photon disappears in the vicinity of a nucleus, and an electron and positron appear in its place.

Particulate Radiation
Fast-moving atomic or subatomic particles that may be charged positively or negatively or not at all.

Peak Power (P_p)
The maximum power density during the on time for a pulsed wave system.

Permissible Environment
Operational environment in which host country military and law enforcement agencies have control as well as the intent and capability to assist operations that a unit intends to conduct.

Permissible Exposure Limit (PEL)
The value to which an individual may be exposed without exhibiting damaging biological effects and is based on the emitter's frequency.

Photochemical Reaction
A chemical reaction which is induced by the absorption of energy in the form of visible, infrared, or ultraviolet radiation.

Photoelectric Effect
An "all or none" energy loss where gamma rays impart all of their energy into an electron.

Pleural Effusion:
When too much fluid collects between the lining of the lung and the lining of the inside wall of the chest.

Positron
Created when a proton changes into a neutron and a positron because there are too many protons in the n:p ratio.

Potential Energy
Energy of position.

Pulse Repetition Frequency (PRF)
The number of times the signal is on per unit of time.

Pulse Width (PW)
The length of time the signal is on for a pulsed wave system.

Quality Factor (Q)
A dimensionless quantity assigned to each type of radiation that allows doses to be normalized in relation to each other.

Radiation
Energy in the form of waves or moving subatomic particles emitted by an atom or other body as it changes from a higher energy state to a lower energy state.

Radiation Absorbed Dose (RAD)
The amount of radiation absorbed by the tissue.

Radioactive Decay
The spontaneous disintegration or transformation of an atom in an attempt by that atom to reach a stable state.

Radioactive Material (RAM)
Material which contains unstable (radioactive) atoms that give off radiation as they decay or transform.

Radioactivity
The spontaneous emission of matter or energy from the nucleus of an unstable atom.

Radioisotopes
Unstable isotopes that, in an attempt to become a stable atom, emit energy in the form of radiation.

Regulated Area
An area under the supervisor's control where entry and exit are restricted and controlled to prevent exposure to hazards. An area shall be established when a requirement in 29 CFR 1910 or 29 CFR 1926 exists, or when BE determines that employees entering the area might be exposed to a hazard unless access is controlled.

Short Term Exposure Limit (OEL- STEL)
A time-weighted exposure for a 15 minute (or shorter) period which shall not be exceeded during the work day. The definition of STEL is different in 29 CFR 1910.1000 (a) (5) (ii) and in the TLV Booklet. The definition must correspond to the reference being cited. As with other OELs, OEL-STELs are the most stringent limits found in the latest TLV Booklet, in 29 CFR 1910 Subpart Z, and in AFOSH Standards for specific substances.

Short-Term Public Emergency Exposure Guideline (SPEGL)
An acceptable peak concentration for unpredicted, single, short-term emergency exposures of the general public. These limits do not apply to occupational exposures.

Specific Absorption Rate (SAR)
An expression of how much RFR energy is imparted to each kilogram of biological body mass per second. SAR is expressed in units of watts per kilogram (W/kg).

Specular Reflection
Situations where a laser beam is reflected from shiny, mirror-like surfaces.

Spontaneous Fission
Spontaneous fission is a natural mode of decay in which nuclei disintegrate.

Stakeholders
Any individual who is affected by the content of the communication and/or will be making decisions based on the information provided.

Stratigraphy
The layering of rock or ice strata, from which information on succession, age relations, and origin can be deduced.

Threshold Limit Values—(TLVRs)
Exposure guidelines published annually by the American Conference of Governmental Industrial Hygienists (ACGIH) in Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. TLVRs are employed as OELs when they are more stringent than the OSHA PELs.

Time-Weighted Average (OEL-TWA)
Eight-hour average concentration for which the average is mathematically adjusted for the duration of exposure. The method for calculating OEL-TWAs is shown in 29 CFR 1910.1000 (d) and in the TLV Booklet.

Toxicology Assessment
Process of estimating the human toxicological impact of a specific material based on published and unpublished literature sources and taking into consideration: uptake, metabolism/biotransformation, transport and storage, and excretion including acute (short-term) and chronic (long-term) human health endpoints.

Transmission Line
Carries the RFR signal from the transmitter to the antenna.

Transmitter
The part of an RFR emitter that generates the RFR signal.

Uncontrolled Environments
An area where exposures may be incurred by people who have no knowledge or control of the hazard.

Wavelength
The distance from one peak of a wave to the next peak of a wave.