DEPARTMENT OF ENERGY	**LESSON PLAN**
Course Material	Topic: Radiological Aspects of Plutonium

Objectives:

Upon completion of this lesson, the participant will be able to:

1. Identify the radiological properties of plutonium.
2. Identify the biological effects of plutonium.
3. Identify special controls and considerations required for plutonium operations.
4. Describe appropriate instruments, measurement techniques, and special radiological survey methods for plutonium.
5. Describe personnel protection requirements and dose control techniques for plutonium.

Training Aids:

Overhead Transparencies (OTs): OT 8.1 – OT 8.12 (may be supplemented or substituted with updated or site-specific information)

Equipment Needs:

Overhead projector

Screen

Student Materials:

Student's Guide

References:

American National Standards Institute, ANSI/ANS*, Criticality Accident Alarm Systems*, 1986.

American National Standards Institute, ANSI/ANS 8.1, *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors,* 1983.

American National Standards Institute, ANSI/ANS 8.19, *ANS Administrative Procedures for Nuclear,* 1984.

ICRP Publication 30 Part 4, *Limits for Intakes of Radionuclides by Workers: an Addendum*, 1988.

U.S. Department of Energy, DOE-STD-1128-98, *Guide of Good Practices for Occupational Radiological Protection in Plutonium Facilities*, 1998.

U.S. Department of Energy, DOE-STD-1121-99, *Internal Dosimetry*, 1999.

U.S. Department of Energy, DOE-STD-1098-99, *Radiological Control*, 1999.

U.S. Department of Energy, DOE G441.1-7, *Portable Monitoring Instrument Calibration,* 1999.

U.S. Department of Energy, Radiological Control Technical Position 2001-01, *Questions and Answers Concerning Acceptable Approaches to Implementing Bioassay Program Requirements*, 2001.

I. Introduction

Show OT 8.1 and OT 8.2.

State objectives.

The guidance in DOE-STD-1128-98, *Guide of Good Practices for Occupational Radiological Protection in Plutonium Facilities,* should be reviewed in detail prior to conducting an assessment of plutonium facilities. The following is a brief overview of the radiological aspects of plutonium.

Review DOE-STD-1128-98, *Guide of Good Practices for Occupational Radiological Protection in Plutonium Facilities.*

II. Background

Plutonium was first synthesized in the winter of 1940-41 by a team of scientists at the University of California. Its potential use in weapons was quickly identified, and much of the effort of the Manhattan Project was in the production of sizable quantities of plutonium. Other uses for plutonium include use as:

- Reactor fuel
- Heat sources in thermoelectric generators to power satellites
- Components in portable neutron sources

Plutonium is a silvery-white metal that readily oxidizes to a dull gray color. It can be found in a variety of physical and chemical forms. Several of the chemical forms (including the pure metal) are pyrophoric, so care must be exercised in handling the material. Because of the pyrophoric nature of plutonium and its alloys, the preferred form for storing, shipping, and handling is as plutonium oxide.

Pyrophoric = able to ignite spontaneously

III. Radiological properties of plutonium

A. Isotopes

There are 15 isotopes of plutonium, all radioactive, beginning with Plutonium-232 and ending with Plutonium-246. The radioisotopes of primary interest are Plutonium-238, Plutonium-239, and Plutonium-240, all of which are primarily alpha-emitters.

Obj. 1
Identify the radiological Properties of plutonium.

Show OT 8.3.

1. Plutonium-238 (half-life = 87.7 yrs) is most commonly used as a heat source in thermoelectric generators. Because of its heat production, care must be taken in handling gram or larger quantities, as it could melt plastic or ignite other materials.

2. Plutonium-239 (half-life = 24,000 yrs) is the primary component of plutonium reactor fuel (>85%) and weapons grade plutonium (>90%), with Plutonium-240 (half-life = 6,560 yrs) constituting most of the remainder in both cases.

3. Plutonium radioisotopes emit relatively few high-energy gamma rays, so kilogram quantities can often be processed without serious gamma dose problems. However, small amounts of some radioisotopes or decay products can increase external dose. For example, Plutonium-241 decays by beta emission to Americium-241, which emits a 60-keV gamma ray. This can be a significant source of dose to hands in glove boxes.

4. Neutron dose rates from spontaneous fission and from alpha-neutron reactions with light elements may be significant (e.g., 1 kg of Pu-F_4 (Pu-238) would have a contact neutron dose equivalent rate of 4800 rem/hr).

B. Biological effects of internally deposited plutonium

Show OT 8.4.

The primary hazards from the most common chemical form of plutonium (PuO_2) are inhalation and ingestion. This chemical form is relatively insoluble. Therefore, uptake through the gastrointestinal (GI) system following an ingestion is small.

Obj. 2
Identify the biological effects of plutonium.

Inhaled plutonium can remain in the lungs for a considerable time before being removed through the lymph system.

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Plutonium is difficult to remove from the body. The primary method is through the administration of chelating agents as soon after the intake as possible. Trained medical personnel are needed to administer chelating agents.

The plutonium that enters the systemic system is mostly translocated to the liver and the bone (as is discussed in the following section). Accordingly, development of cancer in these organs and in the lungs are of particular interest in evaluating long-term effects from intakes of plutonium.

C. Survey techniques

Show OT 8.5.

Obj. 3
Identify special controls and considerations required for plutonium operations.

A radiation protection program in a plutonium facility shall ensure the detection of all types of radiation (i.e., alpha, beta, gamma, x-ray, and neutron) over large energy ranges. Alpha-sensitive instruments are necessary for most contamination control surveys.

Continuous air monitors (CAMs), sample extraction lines that go to CAMs, and continuous radiation dose monitors should be placed outside the glove boxes and hoods.

Neutron surveys become important when processing tens of grams of Plutonium-238 or hundreds of grams of mixed isotopes of plutonium, particularly compounds (i.e., PuO_2, PuF_4). The neutron survey is important in instances where photon shields, such as leaded glass, are used. Such shields normally stop all of the charged particles, most of the low-energy photons, and essentially none of the neutrons. Under these circumstances, neutron radiation is likely to be the major contributor to whole body dose.

Exposure rate surveys are normally conducted with photon-sensitive instruments with known energy responses for photons with energies $\geq$ 10 keV.

Monitoring practices include, but are not limited to, the following:

Show OT 8.6.

- Contamination surveys of the workplace
- Release surveys
- External exposure rate surveys
- Airborne radioactivity surveys (both real time (CAMs) and historical (fixed air head))
- Routine surveillance by a Radiological Control Technician

All workplaces shall be monitored for contamination levels on a regularly scheduled basis. The frequency of such surveys will depend on the potential for dispensability of the radioactive material. As a minimum, all gloves, work surfaces, floors, and equipment within the workplace should be surveyed.

Airborne radioactivity surveys should be performed for:

- Prompt detection of airborne contaminants for worker protection
- Personnel dose assessment
- Monitoring of trends within the workplace
- Special studies

Intakes

In most plutonium facilities, the primary radiological hazard is the potential for internal intakes of plutonium. This hazard must be controlled by appropriate facility and equipment design, contamination control procedures, and protective clothing/equipment.

Plutonium transferred from the initial entry site is assumed to be translocated to the liver (45%) and the bone (45). Retention half-life in the liver is 20 yrs and in the bone is 50 yrs, according to International Commission on Radiological Protection (ICRP) Publication 30.

Per ICRP Publication 48, studies have indicated an average partitioning of plutonium between liver and bone of 30% and 50%. However, due to high individual variability, use of the 45% liver and 45% bone partitioning is still recommended.

Control must be verified by a bioassay program. Urinalysis is the most common technique, but fecal analysis and *in vivo* monitoring may also be appropriate.

DOE-STD-1121-99, *Internal Dosimetry,* provides technical guidance on internal dosimetry programs, including enhanced workplace monitoring for instances where there is a technology shortfall, such as for plutonium. This standard should be reviewed prior to conducting assessments of internal dosimetry programs.

Review DOE-STD-1121-99, *Internal Dosimetry.*

Discuss technology shortfall - routine bioassay cannot reliably detect exposures of 100 millirem.

The standard also discusses appropriate evaluation of bioassay results.

D. Monitoring instruments

Show OT 8.7.

Portable instruments should be calibrated in accordance with DOE G441.1-7, *Portable Monitoring Instrument Calibration*. DOE-STD-1128-98 has additional guidance on monitoring instrumentation.

Obj. 4
Describe appropriate instruments, measurement techniques, and special radiological survey methods for plutonium.

Facilities that deal with unencapsulated plutonium should have continuously operating effluent monitors to determine whether or not plutonium is being released to the environment.

Criticality alarm systems (gamma or neutron) should be provided in each area where an accidental criticality is possible.

E. Sources of external dose

External dose control for plutonium is primarily concerned with photon dose rates from handling plutonium in a glove box and from the neutron dose rate from some mixtures of plutonium.

Show OT 8.8.

While significant high-energy penetrating photons are not commonly associated with plutonium, low-energy photons (x- and gamma-rays) can create significant dose rate problems to extremities. This is particularly a concern when large amounts of Plutonium-238, Plutonium-241, or Americium-241 (from the decay of Plutonium-241) are present.

Neutrons can also represent a potentially significant dose due to spontaneous fission (alpha, neutron) reactions or neutron induced fission. The neutron dose is largely determined by the radioisotope and other materials near the source.

F. Control of external dose

Show OT 8.9.

External dose control is accomplished with traditional dose reduction techniques:

- Time (minimize)
- Distance (maximize)
- Shielding (use as needed)

Long-handled tongs, for example.

Other work practices, including good housekeeping and specialized tool and equipment design, can reduce external dose, as well.

G. Techniques for internal dose control

Show OT 8.10.

The confinement system is a series of physical barriers that, together with a ventilation system, minimizes the potential for release of radioactive material into work areas and the environment under normal and abnormal conditions, thereby minimizing internal dose.

The term "containment" is also used for "confinement."

Generally, three confinement systems are used to achieve the confinement system objectives at plutonium handling facilities. They consist of the following:

- Primary confinement is provided by piping, tanks, glove boxes, encapsulating material, and the like, and any off-gas system that controls effluent from within the primary confinement. It provides confinement of the area immediately surrounding the hazardous material.
- Secondary confinement is provided by the walls, floor, roof, and associated ventilation exhaust systems of the cell or enclosure surrounding the process material or equipment. Except in the case of glove box operations, the area inside this barrier is usually unoccupied; it provides protection for operating personnel.
- Tertiary confinement is provided by the walls, floor, roof, and associated ventilation exhaust system of the facility. It provides a final barrier against release of hazardous material to the environment.

Different devices may be used to confine and control radioactive material. The selection of the appropriate device will depend on the quantity of material, its form, and the operations to be performed.

Fume hoods may be used for some operations with plutonium, depending on the quantity and dispersability of the material. In general, plutonium fume hood operations shall be limited to wet chemistry processes and less than 100 mg of plutonium.

Higher levels of plutonium are generally handled in glove boxes. Care should be taken in the design of the glove box to ensure confinement of the material and any fire.

Ventilation may also be employed to confine plutonium, although it usually is used in conjunction with other measures.

H. Personnel protection

Show OT 8.11.

Obj. 5
Describe personnel protection requirements and dose control techniques for plutonium.

Workers in plutonium facilities need to be appropriately trained on the hazards. DOE has developed DOE/EH-0425, *Plutonium Facilities Training*. This document provides DOE's guidance on expectations for training of plutonium workers.

DOE/EH-0425 *Plutonium Facilities Training* is currently being updated and will be reissued as a DOE handbook. DOE/EH-0425 is currently available from the EH-52 website:
ttp://tis.eh.doe.gov/whs/rhmwp/RST/rstmater.htm

The use of personal air sampling programs should be considered to monitor individual workers for exposure to airborne plutonium. Section 4.4.4 of DOE-STD-1121-98, *Internal Dosimetry*, discusses use of breathing zone or personal air monitoring when there is a technology shortfall (i.e., the derived investigation level is less than the minimum detectable activity). Technology shortfalls are common for routine plutonium bioassay programs.

In addition, DOE has issued guidance on use of air monitoring results when there is a technology shortfall in Radiological Control Technical Position (RCTP) 2001-01, *Questions and Answers Concerning Acceptable Approaches to Implementing Bioassay Program Requirements*.

Review Radiological Control Technical Position 2001-01, *Questions and Answers Concerning Acceptable Approaches to Implementing Bioassay Program Requirements*

In part, RCTP 2001-01 states that, when there is a technology shortfall for bioassay and air monitoring results indicate exposures greater than 100 millirem in a year are likely, one should assess dose based on the air monitoring results.

As a minimum, personnel who perform operations in controlled areas should wear coveralls and shoe covers. For inspections or visits, lab coats and shoe covers may be permissible. When contaminated wet areas are to be entered, water-repellent (plastic or rubber) clothing shall be worn. No personal outer clothing should be permitted under coveralls.

Hands should be protected by a minimum of two barriers; for example, at least one pair of surgeon's gloves and one pair of rubber gloves should be worn.

Protective clothing should be removed at the step-off pad, and personnel monitoring for contamination shall be performed.

Respiratory protection equipment shall be readily available. Respiratory protection equipment should be used for all bag-out operations, bag and glove changes, and any situation involving a potential or actual breach of confinement. Protection, in the form of air-purifying or atmosphere-supplying respirators, shall be used whenever concentrations of radionuclides in the air are likely to exceed the applicable DACs.

DAC = Derived Air Concentration, a 10 CFR 835 limit for airborne radioactivity.

I. Inventory control and accountability requirements

Show OT 8.12.

Real-time or near real-time accountability systems should be incorporated if possible.

J. Criticality safety considerations

Criticality alarm systems (gamma or neutron) shall be provided in each area where an accidental criticality is possible.

Criticality safety requirements may include: ANSI/ANS 8.3-1986*, Criticality Accident Alarm Systems*; ANSI/ANS 8.1-1983, *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*; and ANSI/ANS 8.19-1984, *ANS Administrative Procedures for Nuclear Criticality.*

It is important to review site requirements documents prior to conducting the assessment.

All DOE facilities that possess sufficient quantities and kinds of fissile material to potentially constitute a critical mass shall provide nuclear accident dosimetry.

Reference 10 CFR 835.1304.

Summarize lesson.

Review objectives.

Ask for questions.

DEPARTMENT OF ENERGY	**LESSON PLAN**
Course Material	Topic: Radiological Work Permits

Objectives:

Upon completion of this lesson, the participant will be able to:

1. Identify types of job hazards that are not addressed by Radiological Work Permits (RWPs).
2. Describe the two basic types of RWPs.
3. Determine the types of jobs that may and may not be worked under the controls imposed by RWPs.
4. Identify typical time limits for the two basic types of RWPs.
5. List essential elements of an effective RWP.
6. List RWP program elements that may be included in a radiological assessment.

Training Aids:

Overhead Transparencies (OTs): OT 9.1 – OT 9.11 (may be supplemented or substituted with updated or site-specific information)

Equipment Needs:

Overhead projector

Screen

Student Materials:

Student's Guide

References:

U.S. Department of Energy, DOE-STD-1098-99, *Radiological Control*, 1999.

U.S. Department of Energy, 10 CFR Part 835, *Occupational Radiation Protection*, 1998.

U.S. Department of Energy, Order 440.1A, *Worker Protection Management for DOE Federal and Contractor Employees,* 1998.

I. Introduction

Show OT 9.1 and OT 9.2.

State objectives.

10 CFR Part 835.501(d) requires written authorizations to control entry and perform work in radiological areas, commensurate with the radiological hazards. DOE-STD-1098-99, *Radiological Control*, July 1999, Chapter 3, Part 2, provides guidance on DOE's expectations for such written authorizations.

Review Chp 3, Part 2 of DOE-STD-1098-99, *Radiological Control*, July 1999

These written authorizations may take a variety of forms tailored to the work processes involved. Often, the form will be that of a Radiological Work Permit (RWP), discussed in detail below.

II. Radiological Work Permits (RWPs)

Obj. 1
Identify types of job hazards that are not addressed by Radiological Work Permits (RWPs).

A. Purpose

The RWP is designed to document the radiological conditions and associated controls in a work area. The RWP should be integrated with other work authorizations that address safety and health issues, such as those for industrial safety and hygiene, welding, and confined space entry.

Articles 311 and 312 of DOE-STD-1098-99 provide guidance on preparing work control procedures consistent with the principles of Integrated Safety Management. This includes use of multidiciplinary teams to prepare work control procedures for tasks involving significant types of hazards and referring to DOE Order 440.1A, *Worker Protection Management for DOE Federal and Contractor Employees*.

B. Typical RWP process

Show OT 9.3.

The process may be different at your site or facility.

1. Requester submits an RWP request form.

2. Radiological Control Supervisor accepts form, collects additional job information as necessary, and assures that completion of

appropriate radiological surveys to be performed in the work area.

3. Radiological Control Technicians, or other appropriately trained and authorized personnel, perform surveys, analyze samples, and report results.

4. RWP controls are established based on the results of the surveys.

5. Radiological Control personnel, in consultation with relevant technical staff, complete, distribute and implement the RWP.

6. Radiological Workers and Radiological Control personnel review completed RWP, prior to start of job, during pre-job briefs, and/or ALARA reviews.

Show OT 9.4.

7. Radiological Worker/Supervisor advises Radiological Control personnel when job is complete (so RWP can be terminated).

8. Radiological Control personnel maintain surveys and RWP documentation.

C. Types of RWPs

Show OT 9.5.

There are two basic types of Radiological Work Permits:

Obj. 2
Describe the two basic types of RWPs.

- Job-specific RWP
- General RWP

The job-specific permit is used for jobs which present a greater potential for significant radiation dose, airborne radioactivity, or spread of contamination, and which involve "hands on" work.

Examples of jobs that would likely require job-specific RWPs include those where work is:

- Performed with detailed, specific, written work procedures, approved in advance by Radiological Control personnel

Obj. 3
Determine the types of jobs that may and may not be worked under the controls imposed by RWPs.

- "Hands-on" work performed infrequently on radiological systems (e.g., valve replacement in process buildings)

- Performed in areas in which the radiological conditions have no history of remaining stable

The general RWP typically is used for jobs with less potential for health physics concerns and for routine, repetitive jobs that do <u>not</u> involve "hands on" work.

Examples of jobs that may be worked under a general RWP include:

- Routine tours, inspections, inventories, valve lineups, equipment tagouts, surveys, and equipment operation.

- Work routinely performed on nonradiological systems (e.g., fire protection systems in shut-down process buildings).

- Routine operations involving radioactive material for which the radiological conditions have a history of remaining stable.

Keep in mind that there may be a need for other (nonradiological) permits or authorizations to safely perform these jobs. For example permits may be needed to address nonradiological hazards, such as: electrical, confined space, asbestos, hazardous materials, respiratory protection, fire, heavy equipment and scaffolding.

D. Time limits

Show OT 9.6.

Obj. 4
Identify typical time limits for the two basic types of RWPs.

The job-specific RWP usually remains in effect only for the duration of the job (typically less than 30 days).

The general RWP typically is approved for a period of time of one year or less.

E. Elements of an RWP include:

Show OT 9.7.

Obj. 5
List essential elements of an effective RWP.

- Description of work (detailed)

"Valve work" is not a detailed work description.

- Radiological conditions (contamination, airborne, radiation levels) in the work area
- Dosimetry (TLD badge, self-reading dosimetry, special dosimetry) requirements
- Requirements for a pre-job briefing, if necessary

Briefings are needed most for elevated radiation or contamination levels: workers in High Contamination Areas need briefings more than workers in Contamination Areas.

- Radiological Control Technician coverage (start of job, continuous, intermittent)
- Training requirements to work in the area
- Protective clothing requirements

Show OT 9.8.

- Respiratory protection equipment requirements
- Stay time requirements

Discuss stay time, accidents, and alarms.

- Radiological conditions that may limit work or void the RWP

Discuss staff rotation, alarming dosimetry, planning, and shielding.

- Special dose reduction (ALARA) or contamination reducing measures to be considered
- Special personnel contamination monitoring requirements

- Work document number (if used)
- Unique RWP identification number

Show OT 9.9.

- Date of permit issue and expiration date
- Signatures of Radiological Worker and supervisor (attesting to their understanding of RWP requirements and agreement to follow) and Radiological Control staff

If time allows, show examples of contemporary RWPs, highlighting required information and radiological controls.

F. RWP Elements for Radiological Assessment

Obj. 6
List RWP program elements that may be included in a radiological assessment.

The following are RWP program elements which may be reviewed as part of a radiological assessment:

Show OT 9.10.

- RWPs appropriately required for activities and areas
- Completeness of information on RWPs
- Adequacy of radiological surveys to support RWP
- Worker adherence to RWP requirements
- RWP appropriately reviewed and approved

Show OT 9.11.

- Adequacy of worker monitoring (TLDs, bioassay, air monitoring RCT coverage) specified on RWP
- ALARA considerations included in RWP
- RWP program implemented in accordance with written procedures

Summarize lesson.

Review objectives.

Ask for questions.

DEPARTMENT OF ENERGY	**LESSON PLAN**
Course Material	Topic: Contamination Containment and Temporary Control Measures

Objectives:

Upon completion of this lesson, the participant will be able to:

1. Describe what temporary engineered radiological controls can be used to reduce or eliminate contamination spread.
2. Describe why engineered and administrative controls are needed.

Training Aids:

Overhead Transparencies (OTs): OT 10.1 – OT 10.5 (may be supplemented or substituted with updated or site-specific information)

Equipment Needs:

Overhead projector

Screen

Student Materials:

Student's Guide

References:

U.S. Department of Energy, DOE-STD-1098-99, *Radiological Control*, 1999.

U.S. Department of Energy, 10 CFR Part 835, *Occupational Radiation Protection*, 1998.

U.S. Department of Energy, DOE G441.1-9, *Radioactive Contamination Control Guide,* 1999.

U.S. Department of Energy, DOE-STD-1121-99, *Internal Dosimetry*, 1999.

U.S. Department of Energy, Radiological Control Technical Position 2001-01, *Questions and Answers Concerning Acceptable Approaches to Implementing Bioassay Program Requirements*, 2001.

I. Introduction

10 CFR Part 835, *Occupational Radiation Protection*, specifies contamination control requirements in Subpart L. DOE G441.1-9, *Radioactive Contamination Control Guide,* provides guidance on meeting the requirements. Chapters 3 and 4 of DOE-STD-1098-99, *Radiological Control*, also provide guidance on meeting the requirements and additional information for implementing an effective contamination control program. All of these documents should be reviewed prior to conducting an assessment.

> Show OT 10.1.
>
> State objectives.
>
> Review
> 10 CFR Part 835, *Occupational Radiation Protection*
> DOE G441.1-9, *Radioactive Contamination Control Guide,* 1999
> DOE-STD-1098-99, *Radiological Control*

II. Contamination containment and temporary control measures

Minimization of internal dose

The minimization and control of internal dose should be conducted in accordance with the following hierarchy of controls:

> Show OT 10.2.

1. Engineered controls, including containment of radioactive material at the source wherever applicable, should be the primary method of minimizing airborne radioactivity and internal dose to workers.

   Engineered controls are devices such as glove boxes, glove bags, portable filtration units, and containment tents. They should be used to prevent worker inhalation of radionuclides.

   Portable and fixed/permanent shielding using dense materials (lead) or portable plastic interlocking fluid filled containers are also engineered features, used to minimize external radiation dose.

> Obj. 1
> Describe what temporary engineered radiological controls can be used to reduce or eliminate contamination spread.

The use of these devices reduces the spread of contamination, cleanup time, and decontamination costs. These measures help maintain doses ALARA. In addition, they can reduce the need for respirators and the impact on work in nearby areas.

Obj. 2
Describe why engineered and administrative controls are needed.

Engineered controls should be used in accordance with technical instructions, proper training, and effective administrative controls

Site-specific manuals should contain generic instructions on the design, controls, training, and use of engineered controls.

2. Administrative controls, including access restrictions and the use of specific work practices designed to minimize airborne contamination, should be used as the secondary method to minimize worker internal dose.

Show OT 10.3.

3. Only when engineered and administrative controls have been applied and the potential for airborne radioactivity still exists, should personnel protective equipment, including use of respiratory protection, be considered.

   Chapter 3 of DOE-STD-1098-99 discusses:
   Access controls for Contamination Areas
   Controlling the spread of contamination
   Monitoring for contamination.

   Appendix 3 C*, Contamination Control Practices*, includes recommended selection of protective clothing, and a recommended sequence for donning and doffing.

   Use of respiratory protection should be considered under the following conditions:

   Show OT 10.4.

   Air-supplied respirators, for example

   - Entry into posted Airborne Radioactivity Areas
   - During breach of contaminated systems or components
   - Work in areas or on equipment with removable contamination levels greater than 100 times the values in Table 2-2 of DOE-STD-1098-99
   - During work on contaminated or activated surfaces with the potential to generate airborne radioactivity

   The selection of respiratory protection equipment should include consideration of worker safety, comfort, and efficiency. The use of positive pressure respiratory protection devices is recommended wherever practicable to alleviate fatigue and increase comfort.

Respirators can provide adequate protection for workers in an airborne radioactivity environment, but engineered controls may be more practical. By using engineered controls instead of respirators, the worker is not subjected to the stresses created by wearing a respirator. It is more difficult to breath and communicate when wearing a respirator. Vision is impaired, and the respirator is not comfortable. Productivity can therefore be improved by using engineered features instead of respirators.

To minimize intakes of radioactive material by personnel, smoking, eating, or chewing shall not be permitted in Contamination, High Contamination, Airborne Radioactivity Areas, or Radiological Buffer Areas established for contamination control purposes.

Contamination should be contained at its source. The principle is to prevent contamination spread from occurring. The most effective methods based on sound ALARA principles should be used. All controls should be documented and clearly controlled by RWPs.

Respirators may be appropriate for simple, straightforward jobs.

In specific situations the use of respiratory protection may be contraindicated due to physical limitations or the potential for significantly increased external dose.

Show OT 10.5.

Example: Work in high radiation fields and airborne radioactivity.

In such situations, written authorization should be obtained from the line organization manager and the Radiological Control Manager prior to incurring internal dose. Specific justification of the need to accept the dose, including a description of measures taken to mitigate the intake of airborne radioactivity, should be documented as part of the radiological work documentation.

The use of personal air sampling programs should be considered to monitor individual workers for exposure to airborne radioactive material, especially when the use of respiratory protection is contraindicated. This is particularly important when there is a bioassay program technology shortfall (i.e., the derived investigation level is less than the minimum detectable activity). Section 4.4.4 of DOE-STD-1121-98, *Internal Dosimetry*, discusses use of breathing zone or personal air monitoring.

In addition, DOE has issued guidance on use of air monitoring results when there is a technology shortfall in Radiological Control Technical Position (RCTP) 2001-01, *Questions and Answers Concerning Acceptable Approaches to Implementing Bioassay Program Requirements*.

Review Radiological Control Technical Position 2001-01, *Questions and Answers Concerning Acceptable Approaches to Implementing Bioassay Program Requirements*

In part, RCTP 2001-01 states that, when there is a technology shortfall for bioassay and air monitoring results indicate exposures greater than 100 millirem in a year are likely, one should assess dose based on the air monitoring results.

Summarize lesson.

Review objectives.

Ask for questions.

DEPARTMENT OF ENERGY	**LESSON PLAN**
Course Material	Topic: Radiological Work Site Mockup Demonstration

Objectives:

Upon completion of this lesson, the participant will be able to:

1. Identify poor radiological work practices, in and around a mock radiological work site.
2. Inspect a typical contamination containment (glove bag).
3. Develop field assessment notes to support findings (hands-on exercise).

Training Aids:

Overhead Transparencies (OTs): OT 11.1 (may be supplemented or substituted with updated or site-specific information)

Materials needed for this exercise are listed on the following pages.

Student Materials:

Student's Guide

References:

U.S. Department of Energy, DOE-STD-1098-99, *Radiological Control*, 1999.

Radiological Work Site Mockup Demonstration Checklist for Module 11

The exercise is a mock-up demonstration that is performed by the instructors to give the participants an opportunity to assess and identify poor radiological work practices.

The participants should be instructed to identify and make notes of the poor radiological practices during the demonstration. After the demonstration, ask the participants to:

- Identify poor radiological practices
- Make recommendations for improvement

Radiological Work Site Mockup Demonstration Checklist for Module 11
(continued)

Description of Mock-up Demonstration Area

The area is intended to simulate an actual, posted area where radiological work is performed.

White plastic PVC pipes and junctions are used to create a support structure for a heavyweight clear plastic contamination containment (glove bag). The glove bag measures approximately 2 ft wide x 2 ft high x 3 ft long.

The glove bag has four glove ports, which allow the installation of four sets of heavy rubber gloves for Radiological Workers #1 and #2. The bag is suspended from the PVC pipes by "bungee" cords.

Inside the glove bag is a valve, with two shutoff valves installed on both sides. The valves are installed on PVC pipe, which penetrates the glove bag. The penetrations are taped, to ensure a good seal.

Normally a polyethylene (poly) bottle would be connected to the glove bag, to collect any liquid released inside the bag. In this exercise, the poly bottle is intentionally not installed.

Radiological rope barrier and standard signs (which intentionally contain improper wording or incorrect color combinations) surround the posted area, which measures about 15 ft x 15 ft square. One exit, with step-off pad, is provided, through which the actors enter the area.

Directly beneath the glove bag is a simulated area of high radiation called a "hot spot," with a standard label filled-in to indicate the dose rate. A yellow lead blanket is provided to cover (shield) the "hot spot."

The simulated job, which is controlled by a Radiological Work Permit (RWP), is valve removal by Radiological Workers #1 and #2, supported by a Radiological Control (DOE RadCon) Technician, a Quality Inspector, and a DOE Representative.

Radiological Work Site Mockup Demonstration Checklist for Module 11
(continued)

Supplies and Equipment for Mock Exercise

This item is needed:	To:
rubber mallet	install and dismantle PVC pipe support
standard screwdriver	tighten glove hose clamps
pipe wrench	tighten valve connections
"hot spot" blank labels	enter field information on dose rates
"bogus'" radiological signs (RADIATION AREA signs with incorrect wording and/or colors)	simulate erroneous posting of radiological area
step-off pad	simulate radiological area exit
razor knife	cut glove penetrations into bag
yellow tape	seal valve-to-glove bag surfaces
yellow lead blanket	shield "hot spots"
yellow poly bottle	stage in background, outside radiological area
stanchions ("rad rope")	simulate radiological area boundaries
office trash can	serve as a "prop"

Radiological Work Site Mockup Demonstration Checklist for Module 11
(continued)

Setup for Mock Exercise

Complete the following tasks prior to the implementation of the mock-up exercise:

- ❑ Install PVC containment supports, pipe with valve and glove bag.
- ❑ Place a tear in one finger of a glove attached to a glove bag (large enough to stick a finger through).
- ❑ Open both isolation (green-handled) valves.
- ❑ Prepare a "hot spot" label and write "500 mrem/hr" on the label.
- ❑ Stick label onto mock hot spot and place yellow lead blanket over it.
- ❑ String yellow and magenta poly rope through stanchions to establish mock radiological area.
- ❑ Place defective signs (wrong color or wording) onto the rope; for example, "Radiation Zone."
- ❑ Place poly bottle in background (5 ft behind containment supports).
- ❑ Place a yellow plastic waste bag just outside the radiological area.
- ❑ Prepare RWP for this job showing High Radiation Area, Radiological Buffer Area, thermoluminescent dosimeters (TLDs) and pocket dosimeters, continuous Radiological Control Technician coverage, and pre-job briefing required (instructor reviews with the class members in an earlier session).
- ❑ Brief players before mock exercise (see Module 11 of Instructor's Guide).
- ❑ Dress players (include "maternity padding" for DOE Representative).
- ❑ Paint simulated cut on right hand of Worker 2.

I. Introduction

Show OT 11.1.

State objectives.

II. Mockup demonstration

Refer to previous pages for instructions on setting up for the mockup demonstration.

A. Storyboard

Ask participants to observe the demonstration and watch for poor radiological work practices. Encourage participants to write down poor work practices in their student's guide for discussion after demonstration.

Player(s)	Action	Dialogue
Workers #1 and #2	Approach posted radiological area.	
Worker #2	Chews gum and rubs the open cut on his hand.	
Worker #1 Worker #2	Asks Worker #2: Replies:	"Do you have the RWP?" "I thought you had it."
Worker #2	Asks Worker #1:	"Where is that RadCon Technician?"
Worker #1	Replies:	"I haven't seen him."
Worker #1	Pulls out his pocket dosimeter, raps it on the pipe, and reads it. Asks Worker #2:	"Where is your dosimeter?"

Player(s)	Action	Dialogue
Worker #2	Replies:	"I'll just use your reading."
Worker #1	Asks Worker #2:	"Are you ready to get started?"
Worker #2	Replies: Takes a sip from his soft drink and places the cup on the floor.	"In a minute..."
Workers #1 and #2	Enter radiological area.	Engage in small talk: what happened over the weekend, hunting, children.
Worker #2	Sticks used chewing gum to pipe support. Notices green isolation valves are open. Calls out to Worker #1:	"Hey, these valves are open."
Worker #1	Replies to Worker #2:	"So, close them."
Worker #2	Closes only one valve. Comments to Worker #1:	"I wish we had been trained to work on this valve. It sure would be easier if we knew what we were doing and had received a pre-job briefing."
Worker #1	Replies: Sticks finger through a hole in a torn glove bag.	"No big deal, we can wing it."

Player(s)	Action	Dialogue
Worker #1	Works a short minute. Asks Worker 2:	 "Have you seen the replacement valve?"
Worker #2	Points to the valve outside the area and replies: Leaves the area to get the replacement valve.	"It's over there, I'll get it."
Worker #1	Loiters in area, close to "hot spot."	
RadCon Technician	Enters the scene and walks around the area, but does not provide much assistance to the workers. Demonstrate his contamination survey instrument (with a pancake probe).	
DOE Representative and Quality Inspector	Enter the area and engage in small talk with Worker #1.	
Worker #1	Resumes work.	
DOE Representative	Relocates lead blanket, then sits over "hot spot."	
Worker #2	Returns with replacement valve and knocks over his soft drink.	

Player(s)	Action	Dialogue
Worker #1 Worker #2 Worker #1 Worker #2	Continues working. Shakes hands because they have become wet. Complains: Turns to Worker #2 and replies: Shuts the valve off.	 "Hey, there is rusty water in this glove bag." "Well, shut the valve."
Worker #1	Opens the glove bag's zipper and places the replacement valve in the bottom of the glove bag.	
Quality Inspector Worker #2 Quality Inspector	Complains: Reaches into his pocket and offers the Quality Inspector a stick of gum. Replies: Takes the gum.	"My mouth is sure dry." "Would you like a stick of gum." "Sure, thanks."
Quality Inspector	Moves the poly bottle into area and sits on it.	
Quality Inspector Worker #2 Quality Inspector	Reaches into area to "help" Workers #1 and #2 with the job. Asks the Quality Inspector: Replies:	 "How many of these jobs have you done?" "None, I'm new. Matter of fact, I'm scheduled for GERT next Tuesday."

Player(s)	Action	Dialogue
Worker #1 and Worker #2 Worker #1	Remove the defective valve. Look around for the bag to place the valve in. Complains:	 "Where's the bag to put this thing in?"
RadCon Technician	Leaves the controlled area. Returns with the yellow bag and prepares to receive the defective valve from Workers #1 and #2.	
Worker #2	Fumbles about and misses the yellow bag, dropping the valve on the floor.	"OOPS"
RadCon Technician	Picks up the valve and puts it into the plastic bag, laying it on the floor. He leaves the area without monitoring	
Quality Inspector Worker #1 Quality Inspector	Drops his pen into the area of the spill. Picks up the pen and hands it to the Quality Inspector. Accepts the pen and does not request it to be monitored or decontaminated.	
Quality Inspector and DOE Representative	Leave the area.	

Player(s)	Action	Dialogue
Worker #1 Worker #2 Worker #2	Asks Worker #2: Replies: Places lead blanket over the spill.	"What should we do about the spill?" "It's almost breaktime. RadCon will take care of it later."
Worker #1	Picks up bagged valve and throws it into a nearby trash can.	
Workers #1 and #2	Leave the area.	

B. Deliberate errors from mock exercise

- Workers #1 and #2 are dressed differently for the same job
- Protective clothing worn by Worker #1 is not taped at wrists, ankles
- Bearded Worker #1 wearing respirator
- Half-face respirator used (type not recommended for radioactive materials)
- Wrong (yellow) canisters installed in mask
- Worker #2 chews gum
- No RWP copy at work site
- No RadCon Technician present (RWP calls for continuous coverage)
- Worker #1 abuses pocket dosimeter
- Worker #2 has no pocket dosimeter
- Quality Inspector, RadCon Technician, and DOE Representative have no TLD badges
- Worker #2 drinks soft drink in area
- Green isolation valves not closed prior to beginning work
- No pre-job briefing (based on dialogue)
- No training for this job (based on dialogue)
- Torn glove (glove bag not inspected for integrity prior to job start)
- No corrective action to torn glove

Ask participants to identify errors observed during the demonstration. Encourage participants to write down the errors in their student's guide, then discuss each of the errors.

- Replacement valve not taken into area
- Worker #1 loiters in high radiation area while #2 gets replacement valve
- RadCon Technician not actively involved in job assistance
- RadCon Technician does not have proper survey instrument for measuring radiation levels
- DOE Representative moves lead blanket without replacing it to original position
- DOE Representative (pregnant) sits over unshielded hot spot
- Worker #2 has open cut on hand
- Worker #2 creates liquid spill (knocks over soft drink)
- Inappropriate response to spill (covers with lead blanket, no notice to RadCon)
- Quality Inspector is given gum in area and chews it
- Poly bottle not installed for glove bag
- Quality Inspector is in area without having received General Employee Radiological Training (GERT)
- No yellow plastic bag in area to receive old valve dropped onto floor
- Worker #2 drops old valve onto floor (creating another spill)
- RadCon Technician does no monitoring after valve dropped onto floor
- Quality Inspector drops pen into contamination and there is no monitoring or decontamination of the pen
- Worker #1 puts used, contaminated valve into ordinary trash can

NOTE: Participants will detect other errors that are not listed.

Summarize lesson.

Review objectives.

Ask for questions.

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DEPARTMENT OF ENERGY	**LESSON PLAN**
Course Material	Topic: Radiation-Generating Devices

Objectives:

Upon completion of this lesson, the participant will be able to:

1. Identify radiation-generating devices.
2. Describe the basic components of an x-ray machine.
3. Identify the most common use of x-rays.
4. Identify the potential hazards associated with x-rays.
5. Identify the most common use of sealed gamma ray sources and the potential hazards.
6. Identify the most common use of beta and neutron sources and the potential hazards.

Training Aids:

Overhead Transparencies (OTs): OT 12.1 – OT 12.11 (may be supplemented or substituted with updated or site-specific information)

Equipment Needs:

Overhead projector

Screen

Student Materials:

Student's Guide

References:

U.S. Department of Energy, DOE-STD-1098-99, *Radiological Control*, 1999.

U.S. Department of Energy, 10 CFR Part 835, *Occupational Radiation Protection*, 1998.

ANSI N43.2-1989a, *Radiation Safety for X-ray Diffraction and Fluorescence Analysis Equipment*, 1989.

ANSI N43.3-1993, *Installations Using Non-Medical X-ray and Sealed Gamma Ray Sources Energies up to 10 MeV*, 1993.

U.S. Nuclear Regulatory Commission, 10 CFR Part 34, *Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations*, 1992.

U.S. Department of Energy, DOE G441.1-5, *Radiation-Generating Devices Guide,* 1999.

U.S. Department of Energy, DOE G441.1-13, *Sealed Radioactive Source Accountability and Control Guide,* 1999.

U.S. Department of Energy, DOE HDBK-1109-97*, Radiological Safety Training for Radiation-Producing (X-Ray) Devices*, 1997.

I. Introduction

Show OT 12.1 and OT 12.2.

State objectives.

Review 10 CFR 835 radiological worker definition.

10 CFR Part 835, *Occupational Radiation Protection*, includes provisions for exposure to ionizing radiation from DOE activities. Included in the 10 CFR 835 definition of a radiological worker is "operation of radiation producing devices". 10 CFR 835 also specifies requirements for sealed radioactive sources.

II. *DOE* Guidance

Show OT 12.3.

Review DOE G441.1-5, *Radiation-Generating Devices* Guide.

DOE G441.1-5, *Radiation-Generating Devices Guide,* provides guidance on DOE's expectations for controlling exposure from radiation generating devices (RGD). The IG includes a definition of a RGD as "a collective term for devices which produce ionizing radiation including, certain sealed radioactive sources, small particle accelerators used for single purpose applications which produce ionizing radiation (e.g., radiography), and electron generating devices that produce x-rays incidentally."

Show OT 12.4.

Obj. 1
Identify radiation generating devices.

For sealed radioactive sources, refer to DOE G441.1-13, *Sealed Radioactive Source Accountability and Control Guide.*

Review DOE G441.1-13, *Sealed Radioactive Source Accountability and Control Guide.*

Article 365 of DOE-STD-1098-99, *Radiological Control*, provides additional guidance, including the use of ANSI N43.3, ANSI N43.2, and 10 CFR Part 34 for meeting its requirements covering RGDs.

Review DOE-STD-1098-99, *Radiological Control* (Article 365).

DOE HDBK-1109-97*, Radiological Safety Training for Radiation-Producing (X-Ray) Devices*, provides guidance on DOE's expectations for radiation safety training for individuals using RGDs.

Review DOE HDBK-1109-97, *Radiological Safety Training for Radiation-Producing (X-Ray) Devices*

III. X-ray machines

A. Components

X-ray devices have been in existence for about 100 years. Although there are many different designs of x-ray machines, they all have the same basic components. These include a source of electrons, an electrical potential difference to accelerate the electrons, and an anode, or target for the accelerated electrons to strike.

Show OT 12.5.

Obj. 2
Describe the basic components of an x-ray machine.

Usually, the source of electrons in an x-ray machine is a thin wire filament from which electrons are emitted when it is heated by a large electrical current. Controlling the current through the filament, then, becomes a way to control the number of electrons available for acceleration.

The number of electrons moving across the x-ray tube, or the tube current, is adjusted on the x-ray machine control panel with the milliAmpere (mA) control. In some x-ray machines, the mA may be fixed, and not adjustable by the operator.

The electrical potential difference between the cathode (filament) and the anode (or target) is the force that accelerates the electrons. The larger the potential difference, the more kinetic energy the electrons will acquire. The potential difference is measured in units of kilovolts (kV). The energy of the electrons is measured in units of kilo electron volts (keV), with one electron volt being the amount of energy required to move one electron through a potential difference of one volt.

Electrons interact in the target by one of the following mechanisms:

- Excitation
- Ionization
- Bremsstrahlung

The accelerated electrons then strike the anode (or target). The target may consist of various materials, depending on the purpose and design of the x-ray tube. X-ray production is most efficient in high atomic number targets, like tungsten.

When electrons strike and excite target atoms, the kinetic energy of the electrons is deposited in the target as heat. When electrons ionize target atoms, characteristic x-rays will be emitted as electrons from outer shells fill vacancies created by ejected electrons.

When the accelerated electrons simply decelerate (brake) as they come near the large, positively charged nucleus of a target atom, the change in energy resulting from the deceleration is emitted as a bremsstrahlung photon. If the accelerated electron loses all of its energy and essentially comes to rest, then the energy of the bremsstrahlung photon will be equal to the initial kinetic energy of the electron.

B. X-ray energy spectrum

Show OT 12.6.

The energy of the x-ray photons coming out of the x-ray machine is of interest to the users of the machine. The typical energy spectrum from an x-ray machine consists of the characteristic x-rays from the target, which have discrete energies, and the bremsstrahlung photons which have a whole range of energies, the maximum energy depending on the potential difference across the tube. For a typical x-ray machine, the bremsstrahlung photons far outnumber the characteristic x-rays.

Bremsstrahlung is German for "braking radiation."

C. Design features

The cathode and anode of the x-ray tube are enclosed in an evacuated glass tube or envelope. The vacuum is necessary to ensure that the accelerated electrons will interact in the target, and not with gas molecules.

The x-rays are produced in all directions in the target. However, only x-rays directed toward the exit port, or window, will comprise the useful beam.

Several devices are used to control the size of the useful x-ray beam. A lead diaphragm is a sheet of lead with a hole in it. It is placed near the exit port, and restricts the size of the useful beam by absorbing x-rays that don't pass through the hole. The size of the beam is not adjustable with this type of device unless another diaphragm with a different-size opening is used.

For some operations, the size of the useful beam must be adjusted by the operator. An adjustable collimator is essentially a set of movable lead sheets. Two sheets restrict the width of the beam, and two sheets restrict the length of the beam. The operator can then adjust the size of the beam to any desired combination of length and width.

Often, the lowest energy x-rays are not desired in the beam. The low energy x-rays can be filtered out by placing absorbing material (called filters) in the path of the beam. Aluminum or copper is commonly used, depending on the energy of the machine. The addition of filters increases the average energy of the beam, since the lower energy x-rays are removed from the beam when they are absorbed by the filters.

The anode is usually encased in copper, which serves to dissipate the heat. In many x-ray machines, the anode rotates at a high speed, which increases the area of bombardment and therefore is also useful in dissipating heat.

The x-ray tube housing is an insulated metal casing around the glass envelope that provides both electrical and radiation shielding. The housing will intercept most of the x-rays produced in the target that are not part of the useful beam.

D. Common uses and hazards

X-ray machines are most commonly used for radiography, or the examination or inspection of the structure of materials by non-destructive means.

X-ray machines used in medicine are fairly standardized in appearance, and in the way they are installed. That is not true of x-ray machines used for industrial applications. X-ray machines may be fixed installations, mobile units, or completely enclosed cabinet systems. The cabinet x-ray systems are commonly used for security applications (e.g., baggage inspection units).

The major hazard from x-ray machines is the external dose hazard to machine operators and other people in the vicinity. No one should ever be exposed to the primary (or useful) beam. Exposure to leakage radiation (from the housing) and scatter radiation should be reduced by appropriate controls.

Obj. 3
Identify the most common use of x-rays.

The energy of the x-rays required will depend on the density, thickness, and atomic number of the objects or structures to be imaged, or examined. Dense, thick, high atomic number objects or structures require more energetic x-rays.

Show OT 12.7.

Obj. 4
Identify the potential hazard associated with x-rays.

IV. Analytical x-ray machines

Show OT 12.8.

A. Fluorescence analysis

Characteristic x-rays that result from ionization of atoms can be used to identify atoms, since the characteristic x-rays will have energies that are unique to that element. This forms the basis for x-ray fluorescence spectroscopy. A sample to be analyzed is irradiated by a beam of high-intensity x-rays. The x-rays ionize atoms in the sample, which emit characteristic x-rays when the electron shell vacancies created by ionization are filled.

The characteristic x-rays can be analyzed by determining their energy, or by determining their wavelength. Either way, the result leads to information about the elemental composition of the sample.

These instruments are usually completely enclosed. Access doors are provided for changing samples, and the doors are equipped with interlocks to prevent access to the x-ray beam.

The hazard is primarily an external dose hazard to scattered radiation from the components and the sample, and is typically fairly low.

B. X-ray diffraction

When x-rays are scattered by a crystalline solid, they are scattered from the different atoms, but only in certain directions. This technique is used for crystal structure research.

Collimated = focused

The primary beam and the diffracted beams are very small and well collimated. In some types of diffraction equipment, the sample cannot be enclosed in a structure. The primary beam is controlled by a shutter that opens and closes. The major hazard associated with diffraction units is intense, localized exposure from the primary beam to the hands or eyes that can occur during sample changing or beam alignment procedures with the shutter inadvertently open. The primary beam is very small, but may have an intensity of up to 40,000 R/min. At this exposure rate, even short exposures of the hands and fingers could result in severe injury, and potential loss of fingers.

V. Sealed gamma ray sources

Show OT 12.9.

Sealed gamma ray sources are used for a variety of applications in industry. Gamma ray sources are the most common sealed source encountered, although others are used and are discussed later. Radiography is probably the most common use, and may be performed with the gamma rays from sealed sources of Cobalt-60, Cesium-137, or Iridium-192.

Obj. 5
Identify the most common use of sealed gamma ray sources and the potential hazards.

Other uses of sealed gamma ray sources are thickness gauges (e.g., to determine the thickness of sheet metal), level gauges (e.g., to determine a fluid level in a container), and density gauges (e.g., to measure the geologic formation porosity during oil and mineral logging).

The hazard from these sources is primarily an external dose hazard. The most common cause of overexposure incidents with gamma radiography sources results from radiographers failing to perform radiation surveys to verify that the gamma source is back in the shielded position. Also, if mechanical damage to the source encapsulation occurs, radioactive material contamination will be a hazard as well.

VI. Other sealed sources

Show OT 12.10.

Sealed sources of beta particles may be used as thickness gauges (e.g., measurement of dust on filter paper, or gauging thickness of thinner plastics).

Obj. 6
Identify the most common use of beta and neutron sources and the potential hazards.

Neutron sources have a variety of applications and are commonly used in moisture gauges (e.g., determining moisture content in raw materials such as gravel, wood chips, etc.). The fast neutrons emitted by the source are moderated by the hydrogen atoms in the material being measured, and can then be detected with a neutron detector. Of course, the more moisture contained in the material, the more hydrogen atoms will be present.

Fast neutrons moderated (slowed down) to slow neutrons, which are detected.

When an alpha-emitting material is combined with beryllium, the alpha/beryllium reaction results in the formation of Carbon-12 and a neutron. Some common sources of this type are combinations of Americium-241 and Beryllium (AmBe sources) and Plutonium-239 and Beryllium (PuBe sources). Another nuclear reaction that can produce neutrons is the photo-neutron reaction. For this reaction to occur, a gamma-emitting material is combined with beryllium, resulting in the production of neutrons. An example of this type of neutron source is the combination of Antimony-124 and Beryllium (SbBe source).

Neutron sources are also used to some extent for radiography of very dense materials like lead or steel, which otherwise would require very high energy photons to radiograph.

Californium-252 emits neutrons after undergoing spontaneous fission, and therefore serves as a neutron source. Neutrons can also be produced fairly easily by nuclear reactions in certain materials such as beryllium.

The primary hazard from beta and neutron sources is from the external radiation fields they generate. These sources would only become an internal hazard should the source rupture or leak and radioactive material subsequently is inhaled or ingested. An additional hazard of neutron activation exists around neutron sources.

Neutron activation can produce gamma-emitters (external dose concern).

10 CFR 835 Subpart M "Sealed Radioactive Source Control" establishes requirements for accountable sealed radioactive sources. Requirements include provisions for (at intervals not to exceed 6 months):

Review definition of accountable sealed radioactive source.

Discuss 10 CFR 835.3(e) provision to allow 30 day grace period for certain time intervals.

- inventory
- posting
- leak testing

VII. Other radiation-generating devices

Other radiation-generating devices (RGDs) that may be encountered are small particle accelerators (<10 MeV) used for radiography, ion implantation, or the production of incidental photons or particles (neutron generators).

Some RGDs produce radiation incidental to their primary purpose. Examples of devices that produce radiation incidentally are electron beam welders, electron microscopes, and pulse generators.

VIII. Categorizing RGD installations

The ANSI standards referenced earlier categorize RGD installations into the following categories for radiation safety purposes.

Show OT 12.11.

Each category is discussed briefly. The ANSI standards and other referenced documents should be consulted for complete information and requirements for each category.

A. Exempt shielded installations

The RGD and all objects exposed to the source of radiation shall be within a permanent enclosure that, under all circumstances of use, possesses sufficient inherent shielding and prevents inadvertent entry to any part of the body. The exposure at any accessible region 5 cm from the outside surface of the enclosure shall not exceed 0.5 mrem in any one hour.

B. Shielded installation

The RGD and all objects exposed to the source are within a permanent enclosure from which persons are excluded during the irradiation. Some of the requirements for shielded installations include mandatory interlocks, audible and visual warning devices, a "crash" button, and posting of warning signs.

Skyshine is the term used to describe radiation emerging more or less vertically from a shielded enclosure, which then scatters from air molecules to produce radiation at some distance from the source.

C. Unattended installation

The RGD is installed in a single-purpose shielded enclosure, and the design shall ensure that individuals are not exposed to doses exceeding 100 mrem in a year.

D. Open installation

Open installations must be conspicuously posted, and have a conspicuously defined perimeter. The perimeter must delimit the area in which the exposure can exceed 5 mrem in any one hour. The operational staff shall provide constant surveillance. Other requirements include use of survey meters, personnel dosimetry, and temporary shielding.

Summarize lesson.

Review objectives.

Ask for questions.