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DOE HANDBOOK

Radiological Worker Training

Radiological Safety Training for Radiation Producing (X-Ray) Devices

U.S. Department of Energy
Washington, D.C. 20585

AREA TRNG

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Foreword

This Handbook describes an implementation process for training as recommended in Implementation Guide G441.1-1C, Chapter 14, *Radiation Safety Training Guide,* and as outlined in DOE-STD-1098-2008, *DOE Radiological Control* (the Radiological Control Standard - RCS). The Handbook is meant to assist those individuals within the Department of Energy, Managing and Operating contractors, and Managing and Integrating contractors identified as having responsibility for implementing training required by Title 10 Code of Federal Regulations Part 835 Occupational Radiation Protection (10 CFR 835) and training recommended by the RCS (Article 651). This training is intended for the additional standardized training recommended by the RCS. This training may be given to radiological workers to assist in meeting their job-specific training requirements of 10 CFR 835.

While this Handbook addresses many requirements of 10 CFR 835 and recommendations of the RCS, it must be supplemented with facility-specific information to achieve full compliance.

This Handbook contains recommended training materials consistent with other DOE radiological safety training materials. The training material consists of the following three parts:

Program Management Guide - This part contains detailed information on how to use the Handbook material.

Instructor's Guide - This part contains lesson plans for instructor use, including notation of key points for inclusion of facility-specific information and parenthetical recommendations for teaching points.

Student's Guide - This part contains student handout material and also should be augmented by facility-specific information.

This training material is targeted for individuals with a basic knowledge of radiological control. At a minimum, trainees should have completed Radiological Worker II training.

This Handbook was produced in Microsoft Word. Overheads were produced in Powerpoint. Copies of this Handbook may be obtained from the DOE Radiation Safety Training Home Page Internet site (http://www.hss.energy.gov/HealthSafety/WSHP/radiation/RST/rstmater.htm) or the DOE Technical Standards Program Internet site (http://www.standards.doe.gov/).

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Part 1 of 3

Radiological Worker Training

Radiological Safety Training for Radiation-Producing (X-Ray) Devices

Program Management Guide

Coordinated and Conducted for Office of Health, Safety and Security U. S. Department of Energy

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Program Management

Introduction

Purpose and Scope

This program management guide provides guidance for proper implementation of additional standardized training as outlined in the *DOE Radiological Control Standard (RCS).* The guide is meant to assist those individuals within the Department of Energy, Managing and Operating (M&O) contractors, and Managing and Integrating (M&I) contractors identified as having responsibility for implementing the additional standardized training recommended by the *RCS.* Facilities should determine the applicability of this material to support existing programs meant to comply with the training required by 10 CFR 835. Facilities are encouraged to revise these materials as appropriate.

Management Guide Content

The management guide is divided into the following sections:

- Introduction
- Instructional Materials Development
- Training Program Standards and Policies
- Course-Specific Information

Core Training Goal

The goal of the additional standardized training program is to provide a standardized, baseline knowledge for those individuals completing the core training. Standardization of the knowledge provides personnel with the information necessary to perform their assigned duties at a predetermined level of expertise. Implementing a standardized training program ensures consistent and appropriate training of personnel.

Organizational Relationships and Reporting Structure

The DOE Office of Worker Safety and Health Policy (HS-11) is responsible for approving and maintaining the additional standardized training materials.

The establishment of a comprehensive and effective contractor site radiological safety training program is the responsibility of line management and their subordinates. The training function can be performed by a separate training organization, but the responsibility for quality and effectiveness rests with the line management.

Target Audience

Course instructional materials were developed for specific employees who are responsible for knowing or using the knowledge or skills for each course. With this in mind, the participant should never ask the question, "Why do I need to learn this?" However, this question is often asked when the participant cannot apply the content of the program. It is the responsibility of management to select and send workers to training who need the content of the program. When workers can benefit from the course, they can be motivated to learn the content and apply it on their jobs. Care should be taken to read the course descriptions along with the information about who should attend. Participants and DOE facilities alike will not benefit from workers attending training programs unsuitable for their needs.

Prerequisites

A background and foundation of knowledge facilitates the trainee in learning new knowledge or skills. It is much easier to learn new material if it can be connected or associated to what was previously learned or experienced. Curriculum developers who have been involved in preparing instructional materials for the core training know this and have established what is referred to as "prerequisites" for each course.

Certain competencies or experiences of participants were also identified as necessary prior to participants attending a course. Without these competencies or experiences, the participants would be at a great disadvantage and could be easily discouraged and possibly fail the course. It is not fair to the other participants, the unprepared participant, and the instructor to have this misunderstanding.

Training Material

Training materials for this training program consist of a program management guide, an instructor′s guide, and a student′s guide. This material is designed to be supplemented with facility-specific information.

Supplemental material and training aids may be developed to address facility-specific radiological concerns and to suit individual training styles. References are cited in each lesson plan and may be used as a resource in preparing facility-specific information and training aids.

Each site is responsible for establishing a method to differentiate the facility-specific information from the standardized lesson plan material. When additional or facility-specific information is added to the text of the core lesson plan material, a method should be used to differentiate facility information from standardized material.

Exemptions

Qualified personnel can be exempted from training if they have satisfactorily completed training programs (i.e., facility, college or university, military, or vendor programs) comparable in instructional objectives, content, and performance criteria. Documentation of the applicable and exempted portions of training should be maintained.

Qualification of Instructors

The technical instructor plays a key role in the safe and efficient operation of DOE facilities. Workers must be well qualified and have a thorough understanding of the facility's operation, such as use and maintenance of radiation-producing devices. Workers must know how to correctly perform their duties and why they are doing them. They must know how their actions influence other workers′ responsibilities. Because workers' actions are so critical to their own safety and the safety of others, their trainers must be of the highest caliber. The technical instructor must understand thoroughly all aspects of the subjects being taught and the relationship of the subject content to the total facility. Additionally, the instructor must have the skills and knowledge to employ the instructional methods and techniques that will enhance learning and successful job performance. While the required technical and instructional qualifications are listed separately, it is the combination of these two factors that produces a qualified technical instructor.

The qualifications are based on the best industry practices that employ performance-based instruction and quality assurance. These qualifications are not intended to be restrictive, but to help ensure that workers receive the highest quality training possible. This is only possible when technical instructors possess the technical competence and instructional skills to perform assigned instructional duties in a manner that promotes safe and reliable DOE facility operations.

Technical Qualifications

Instructors must possess technical competence (theoretical and practical knowledge along with work experience) in the subject areas in which they conduct training. The foundation for determining the instructor's technical qualifications is based on two factors:

- the trainees being instructed and
- the subject being presented.

The following is an example of a target audience, subject to be taught, and instructor technical qualifications.

TARGET AUDIENCE	SUBJECT BEING TAUGHT	INSTRUCTOR QUALIFICATIONS
Radiation-Producing Device (RPD) Operators and staff associated with operation, maintenance, or radiation safety of RPDs.	Radiological Safety training for Radiation-Producing (X-ray) Devices.	Demonstrated knowledge and skills in radiation protection, above the level to be achieved by the trainees, as evidenced by previous training/education and through job performance.

Methods for verifying the appropriate level of technical competence may include review of prior training and education, observation, and evaluation of recent related job performance, and oral or written examination. Other factors that may be appropriate for consideration include DOE, NRC, or other government license or certification; vendor or facility certification; and most importantly, job experience. To maintain technical competence, a technical instructor should continue to perform satisfactorily on the job and participate in continuing technical training.

Instructional Capability and Qualifications

Qualifications of instructional capability should be based on demonstrated performance of the instructional tasks for the specific course requirements and the instructor's position. Successful completion of instructor training and education programs, as well as an evaluation of on-the-job performance, is necessary for verification of instructional capability. Instructional capability qualification should be granted as the successful completion of an approved professional development program for training instructors. The program should contain theory and practice of instructional skills and techniques; adult learning; and planning, conducting, and evaluating classroom, simulator, laboratory, and on-the-job training activities.

Illustrated talks, demonstrations, discussions, role playing, case studies, coaching, and individual projects and presentations should be used as the principal instructional methods for presenting the instructional training program. Each instructional method should incorporate the applicable performance-based -

principles and practices. Every effort should be made to apply the content to actual on-the-job experience or to simulate the content in the classroom/ laboratory. The appropriate methodology required to present the instructional content will indicate a required level of instructional qualification and skill.

Current instructors' training, education, and job performance should be reviewed to determine their training needs for particular courses. Based on this review, management may provide exemptions based on demonstrated proficiency in performing technical instructor's tasks.
Through training or experience, technical instructors should be able to*:

- Review instructional materials and modify to fully meet the needs of the training group.
- Arrange the training facility (classroom/laboratory or other instructional setting) to meet the requirements for the training sessions.
- Effectively communicate, verbally and non-verbally, lessons to enhance learning.
- Invoke student interaction through questions and student activity.
- Respond to students′ questions.
- Provide positive feedback to students.
- Use appropriate instructional materials and visual aids to meet the lesson objectives.
- Administer performance and written tests.
- Ensure evaluation materials and class rosters are maintained and forwarded to the appropriate administrative personnel.
- Evaluate training program effectiveness.
- Modify training materials based on evaluation of training program.

*Stein, F. *Instructor Competencies: The Standards.* International Board of Standards for Training, Performance and Instruction; 1992.

Selection of Instructors

Selection of instructors should be based on the technical and instructional qualifications specified in the Course-Specific Information section of this guide. In addition to technical and instructional qualifications, oral and written communication skills and interpersonal skills should be included in the process of selecting and approving instructors.

Since selection of instructors is an important task, those who share in the responsibility for ensuring program effectiveness should:

- interview possible instructors to ensure they understand the importance of the roles and responsibilities of technical instructors and are willing to accept and fulfill their responsibilities in a professional manner.

- maintain records of previous training, education, and work experience.

Procedures for program evaluation will include documentation of providing qualified instructors for generic and facility-specific training programs.

Test Administration

A test bank of questions for each course that has an exam should be developed and content validated. As the test banks are used, statistical validation of the test bank should be performed to fully refine the questions and make the tests as effective as possible. The questions contained in the test bank are linked directly to the objectives for each course. In this way, trainee weaknesses can be readily identified and remedial procedures can be put into place. The test outcomes can also be used to document competence and the acquisition of knowledge.

The test banks should also be used by the instructors to identify possible weaknesses in the instruction. If numerous trainees fail to correctly answer a valid set of questions for an objective, the instruction for that objective needs to be reviewed for deficiencies.

Written examinations may be used to demonstrate satisfactory completion of theoretical classroom instruction. The following are some recommended minimal requirements for the test banks and tests:

- Tests are randomly generated from the test bank.
- Test items represent all objectives in the course.
- All test bank items are content-validated by a subject matter expert.
- Test banks are secured and not released either before or after the test is administered.
- Trainees should receive feedback on their test performance.
- For the first administrations of tests, a minimum of 80% should be required for a passing score. As statistical analyses of test results are performed, a more accurate percentage for a passing score should be identified.

Test administration is critical in accurately assessing the trainee's acquisition of knowledge being tested. Generally, the following rules should be followed:

- Tests should be announced at the beginning of the training sessions.
- Instructors should continuously monitor trainees during examinations.
- All tests and answers should be collected at the conclusion of each test.
- No notes can be made by trainees concerning the test items.
- No talking (aside from questions) should be allowed.

- Answers to questions during a test should be provided, but answers to test items should not be or alluded to or otherwise provided.

- Where possible, multiple versions of each test should be produced from the test bank for each test administration.

- After test completion, trainees may turn in their materials and leave the room while other trainees complete their tests.

- Trainee scores on the tests should be held as confidential.

Program Records and Administration

Training records and documentation shall meet the requirements of 10 CFR 835.704.

Training Program Development/Change Requests

All requests for program changes and revisions should be done in accordance with the DOE Technical Standards Program.

Audit (internal and external)

Internal verification of training effectiveness should be accomplished through senior instructor or supervisor observation of practical applications and discussions of course material. All results should be documented and maintained by the organization responsible for Radiological Control training.

The additional standardized training program materials and processes should be evaluated on a periodic basis by DOE-HQ. The evaluation should include a comparison of program elements with applicable industry standards and requirements.

Evaluating Training Program Effectiveness

Verification of the effectiveness of Radiological Control training should be accomplished per DOE-HDBK-1131-2007, "General Employee Radiological Training," and DOE-HDBK-1130-2008, "Radiological Worker Training." In addition, DOE has issued guidelines for evaluating the effectiveness of radiological training through the DOE Operations Offices and DOE Field Offices. For additional guidance, refer to DOE-STD-1070-94, "Guide for Evaluation of Nuclear Facility Training Programs."

Course-Specific Information

Purpose

This section of the program management guide is to assist those individuals assigned responsibility for implementing the *Radiological Safety Training for Radiation-Producing (X-Ray) Devices.*

Course Goal

Upon completion of this training, the student will have a basic understanding of the principles of RPD operation, safety requirements, and classification of various types of radiation- producing devices.

Target Audience

Individuals who have assigned duties as RPD operators; also staff associated with operation, maintenance, and radiation safety of RPDs.

Course Description

This course illustrates and reinforces the skills and knowledge needed for RPD operators in the basics of safe operation of RPDs.

The purpose of this lesson is to provide information on each of the primary RPDs and discuss the applicable rules governing the use of these devices. Utilizing the requirements and recommendations from ANSI N43.2 and ANSI N43.3, this course will establish guidelines for the proper use of common types of installations that:

- Use X-ray diffraction and fluorescence analysis equipment (analytical) and

- Use X-ray machines up to 10 million electron volts (MeV) for non-medical purposes (industrial).

The primary emphasis of these standards and this class is to keep worker exposure to ionizing radiation at levels that are *as low as reasonably achievable* (ALARA) and to ensure that no worker receives greater than the maximum permissible equivalent dose.

This course is designed to be consistent with Article 655 of the *DOE Radiological Control Standard* for individuals who have assigned RPD duties.

Prerequisites

This training material is designed to augment the DOE Radiological Worker core training. As a refresher, this course includes Radiological Worker training material, as applicable to RPD operators, but is not intended to replace Radiological Worker training. The first module of this course may be issued as a self-study. It is a general overview of Radiological Worker topics. The presentation may be adjusted accordingly.

The facility training program should determine the appropriate prerequisites. However, it is recommended that students complete Radiological Worker training and High/Very High Radiation Area training or the equivalent, prior to taking this course.

Length

4-8 hours (depending on facility-specific information)

Test Bank

On a site-by-site basis.

Retraining

Retraining is not required for this course unless it is used to meet 10 CFR 835 training requirements. In that case, retraining every two years is required. Since some of the content is determined on a facility-specific basis, retraining should also be provided as facility-specific information changes.

Instructor Qualifications

Instructors of this course have a major role in making it successful and meeting the specified objectives. Instructors must have related experience and be technically competent. In this course it is imperative that the instructor have the background and experience of working with RPDs. Instructors must be able to relate their own work experience to the workers assigned duties as RPD operators. Instructors must be able to answer specific questions and use a variety of instructional material to meet the objectives.

Education: Minimum of B.S. degree in Health Physics or related discipline is preferred.

Certification: Certification by American Board of Health Physics (ABHP) or National Registry of Radiation Protection Technologists (NRRPT) is preferred.

Experience: At least five years of applied radiological protection experience in an operating radiological facility including experience as a RPD operator is preferred. The areas of experience should include one or more of the following:

- Analytical (fluorescence or diffraction) X-ray devices
- Medical (diagnostic or therapeutic) X-ray devices
- Industrial radiography
- Electron or low-energy accelerators.
- Knowledge of best nuclear industry practices pertaining to radiological protection with respect to RPDs.

Through training or experience, technical instructors should be able to effectively communicate, verbally and non-verbally, lessons to enhance learning.

Materials Checklist

The following checklist should be used to ensure all training materials are available. All materials are provided in Word format.

- Program Management Guide.
- Instructor's Guide.
- Student's Guide.

Bibliography:

<u>DOE standards, handbooks, and technical standards lists (TSLs)</u>. The following DOE standards, handbooks, and TSLs form a part of this document to the extent specified herein.

U.S. Department of Energy, *Guide to Good Practices for Training and Qualification of Instructors*, DOE-NE-STD-1001-91, Washington, D.C., 1991.

U.S. Department of Energy, *Radiological Control Standard*, DOE-STD-1098-2008, Washington, D.C., 2008.

U.S. Department of Energy, Title 10, Code of Federal Regulations, Part 835, *Occupational Radiation Protection*, Washington, D.C., 2007.

<u>Other government documents, drawings, and publications</u>. The following government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise indicated, the issues of these documents are those cited in the contracting document.

U.S. Nuclear Regulatory Commission, Title 10, Code of Federal Regulations, Part 34, Subpart 31, *Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations*, Section 34.31 "Training," Washington, D.C., 1979.

<u>Non-government documents</u>.

American National Standards Institute, *Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment*, ANSI/HPS N43.2**,** American National Standards Institute, New York, NY, 2001.

American National Standards Institute, *American National Standard for General Radiation Safety Installations Using Non-Medical X-Ray and Sealed*

Gamma-Ray Sources, Energies up to 10 MEV, ANSI/HPS N43.3, American National Standards Institute, New York, NY, 2008.

Cooper, L., *An Introduction to the Meaning and Structure of Physics*, Harper & Row, Publishers, New York, NY, 1968.

Shleien, B., *The Health Physics and Radiological Health Handbook*, Revised Edition, Scinta Inc., Silver Spring, MD, 1992.

National Council on Radiation Protection and Measurements, *Radiation Safety Training Criteria for Industrial Radiography*, NCRP Report, No. 61, Washington, D.C., 1978.

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Instructor's Guide

Radiological Safety Training
for Radiation-Producing (X-Ray) Devices

Coordinated and Conducted

for

Office of Health, Safety and Security

U.S. Department of Energy

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Course Goal

Upon completion of this training, the student will have a basic understanding of the principles of radiation-producing device (RPD) operation, safety requirements, and classification of various types of radiation-producing devices.

Other hazards associated with the use of some X-ray machines, such as electrical, mechanical, laser light, and explosives, are not addressed in this course because they are specific to particular machines and procedures. Neither does this course address operating procedures for specific installations. The participants will receive training on the specific operating procedures at the participants′ work site.

Target Audience

Individuals who have assigned duties as RPD operators. Also staff associated with operation, maintenance, and radiation safety of RPDs.

Description

This course illustrates and reinforces the skills and knowledge needed for RPD operators in the basics of safe operation of RPDs.

The purpose of this lesson is to provide information on each of the primary RPDs and discuss the applicable rules governing the use of these devices. Utilizing the requirements and recommendations from ANSI N43.2 and ANSI N43.3, this course will establish guidelines for the proper use of common types of installations that use:

- X-ray diffraction and fluorescence analysis equipment (analytical) and
- X-ray machines with energies up to 10 million electron volts (MeV) for non-medical purposes (industrial).

The primary emphasis of these standards and this course is to keep worker exposure to ionizing radiation at levels that are *as low as reasonably achievable* (ALARA) and to ensure that no individual receives greater than the maximum permissible equivalent dose.

This course is designed to be consistent with Article 655 of the *DOE Radiological Control Standard* for individuals who have assigned RPD duties.

Length

4 - 8 hours (depending on site-specific information).

Terminal Objective

Demonstrate a basic understanding of :

- General radiation protection principles for safe operation of X-ray devices.

Enabling Objectives

When the participants have completed this course, the participants will be able to:

EO1 Describe ionizing radiation.

EO2 Describe what X-rays are, how they are generated, and how they interact with matter.

EO3 Describe the biological effects of X-rays.

EO4 Identify and describe radiation-monitoring instruments and personnel-monitoring devices appropriate for detecting
X-rays.

EO5 Demonstrate a familiarity with DOE dose limits, facility-specific administrative controls, ALARA, and the major methods for controlling and minimizing external exposure.

EO6 Identify and describe protective measures that restrict or control access to X-ray areas and devices, and warn of X-ray hazards; and be able to identify and describe work documents that provide specific procedures to ensure safe operation of X-ray devices.

EO7 Identify and describe the categories of X-ray-producing devices.

EO8 Explain who is responsible for implementing X-ray safety policies and procedures and describe their specific responsibilities.

EO9 Identify causes of accidental exposures.

Regulations

The prime compliance document for occupational radiation protection at Department of Energy (DOE) sites is the Code of Federal Regulations, 10 CFR 835, "Occupational Radiation Protection". The *DOE Radiological Control Standard* provides detailed guidance on good practices acceptable to the Department in the area of radiological control.

The American National Standards Institute (ANSI) details safety guidelines for X-ray devices in two standards, one on analytical (X-ray diffraction and fluorescence) X-ray equipment and another on industrial (nonmedical) X-ray installations (*Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment*, ANSI/HPS N43.2**,** and I *American National Standard for General Radiation Safety Installations Using Non-Medical X-Ray and Sealed Gamma-Ray Sources, Energies up to 10 MEV*, ANSI/HPS N43.3). Guidance for X-ray training is also provided by the Nuclear Regulatory Commission in 10 CFR 19.12 and 10 CFR 34.31.

(Add information on facility-specific requirements documents as applicable.)

Most of the information presented in this course is based on the radiation safety guidelines on X-ray devices contained in ANSI N43.2, which outlines the safety requirements for X-ray diffraction and fluorescence equipment, and N43.3, which outlines the safety requirements for the design, installation, and operation of industrial (nonanalytical) X-ray installations.

Equipment Needs

- Overhead projector
- Screen
- Flip chart
- Markers
- Facility-specific RPD

Student Materials

Student's Guide.

ANSI

The main objectives of ANSI N43.2 and ANSI N43.3 are to keep worker exposure to ionizing radiation at levels below the maximum permissible dose and that are *as low as reasonably achievable* (ALARA). These objectives may be achieved through the following methods:

- Use of emergency controls.

- Using firm administrative controls.
- Using work control documents such as standard operating procedures (SOPs) and radiological work permits (RWPs).
- Maintaining equipment appropriately.
- Employing a comprehensive maintenance and surveillance program.
- Using adequate shielding.
- Maximizing distance from the source.

LESSON SUMMARY

Introduction

Welcome students to the course.

Introduce self to the participants and establish rapport.

Define logistics:

- Safety briefings - exits.
- Restrooms.
- Hours.
- Breaks.
- Sign-in sheets.
- Test - accountability.
- End-of-course evaluation.

Course Goal

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

State Enabling Objectives.

Course Content

Briefly review the content of the course, noting that there is a logical sequence ("flow"), and that as the instructor presents the material, the participants will relate the material covered to the circumstances that they can expect to find in the facility workplace and procedures. (The instructor should insert facility-specific information.)

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TERMINAL OBJECTIVE:

Demonstrate a basic understanding of :

- General radiation protection principles for safe operation of X-ray devices.

ENABLING OBJECTIVES:

When the participants have completed this course, the participants will be able to:

EO1	Describe ionizing radiation.
EO2	Describe what X-rays are, how they are generated, and how they interact with matter.
EO3	Describe the biological effects of X-rays.
EO4	Identify and describe radiation-monitoring instruments and personnel-monitoring devices appropriate for detecting X-rays.
EO5	Demonstrate a familiarity with DOE dose limits, facility-specific administrative controls, ALARA, and the major methods for controlling and minimizing external exposure.
EO6	Identify and describe protective measures that restrict or control access to X-ray areas and devices, and warn of X-ray hazards; and be able to identify and describe work documents that provide specific procedures to ensure safe operation of X-ray devices.
EO7	Identify and describe the categories of X-ray-producing devices.
EO8	Explain who is responsible for implementing X-ray safety policies and procedures and describe their specific responsibilities.
EO9	Identify causes of accidental exposures.

I. MODULE 101 - RADIATION PROTECTION PRINCIPLES

A. OBJECTIVES

i. Module Objective.

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

ii. Objectives.

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

1. Define ionizing radiation.
2. Identify sources of natural and manmade background radiation.
3. Define the DOE dose limits and facility-specific administrative control levels.
4. Describe the ALARA principle.
5. List the three major methods by which external exposure is reduced.

B. ATOMS (*Objective 1*)

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

C. IONIZATION

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

D. RADIATION (*Objective 1*)

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

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

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

X-rays and gamma rays are a form of electromagnetic radiation. X-rays differ from gamma rays in their point of origin. Gamma rays originate from within the atomic nucleus, whereas X-rays originate from the electrons outside the nucleus and from free electrons decelerating in the vicinity of atoms (i.e., bremsstrahlung). Module 102 discusses how X-rays are produced.

E. UNITS

- Roentgen (R), a measure of radiation *exposure*, is defined by ionization in air by x or gamma radiation.

- Rad, a measure of the energy absorbed per unit mass. It is defined for any absorbing material.

- Rem, a unit of equivalent dose, which is the energy absorbed per unit mass times the applicable radiation weighting factor and other modifying factors.

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

F. BACKGROUND RADIATION

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

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

The equivalent dose to the whole body (i.e., at a depth of 1 cm in tissue) from a chest X-ray is 5 - 10 mrem, a dental X-ray is 50 - 300 mrem, and mammography is 0.5 - 2 rem.

G. DOSE LIMITS (*Objective 5*)

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

The following table lists both DOE dose limits and administrative control levels. Administrative control levels are established lower than the DOE limits to ensure that doses are kept below the DOE limits. (*Refer to:10 CFR 835.202-208*)

DOE Dose Limits and Facility-Specific Administrative Control Levels		
	DOE Dose Limits	Facility-Specific Administrative Control Levels
whole body total effective dose	5 rem/year	insert facility-specific value
extremity	50 rem/year	insert facility-specific value
skin	50 rem/year	insert facility-specific value
internal organ committed equivalent dose	50 rem/year	insert facility-specific value
lens of the eye	15 rem/year	insert facility-specific value
embryo/fetus	0.5 rem/term of pregnancy (for the embryo/fetus of workers who declare pregnancy)	insert facility-specific value
minors and public	0.1 rem/year	insert facility-specific value

DOE facilities are designed and operated to reduce personnel doses as far below the occupational limits as reasonably achievable. The dose received by DOE X-ray workers is typically between 0 and 100 mrem per year above the natural background.

H. CAUSES OF ACCIDENTAL EXPOSURES (KEY ITEM) (*Objective 9 Discuss facility-specific incidents*)

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

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

Every year there are numerous X-ray incidents nationwide. Of these, about one third result in injury to a person. The incident rate at DOE laboratories is much lower than the national average.
(*Discuss DOE or industry events or accidental exposures associated with x-ray generating devices*.)

I. ALARA (*Objective 5*)

Because the effects of chronic doses of low levels of ionizing radiation are not precisely known, we assume there is some risk for any dose. The ALARA principle is to keep radiation dose *as low as reasonably achievable,* considering economic and social constraints.

The goal of an ALARA Program is to keep radiation dose as far below the occupational dose limits and administrative control levels as is reasonably achievable. The success of an ALARA Program is directly linked to a clear understanding and following of the policies and procedures for the protection of workers. Keeping radiation dose ALARA is the responsibility of all workers, management, and the radiation-protection organization.

J. REDUCING EXTERNAL DOSE (KEY ITEM) (*Objective 5 Discuss facility-specific methods to reduce external dose.*)

Three basic ways to reduce external doses are to

- Minimize time.
- Maximize distance.
- Use shielding.

Minimize time near a source of radiation by planning ahead. Increase distance by moving away from the source of radiation whenever possible. The dose from X-ray sources is inversely proportional to the square of the distance. This is called the inverse square law, that is, when the distance is doubled, the dose is reduced to one-fourth of the original value. Proper facility design uses the amount and type of shielding appropriate for the radiation hazard. Lead, concrete, and steel are effective in shielding against X-rays.

II. MODULE 102 - PRODUCTION OF X-RAYS

A. OBJECTIVES

i. Module Objective.

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

ii. Objectives.

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

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

B. ELECTROMAGNETIC RADIATION

i. Types of Electromagnetic Radiation. (*Objective 2*)

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

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

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

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

ii. X-Rays and Gamma Rays. (*Objective 2*)

X-rays and gamma rays both ionize atoms. The energy required for ionization varies with material (e.g., 34 eV in air, 25 eV in tissue) but is generally in the range of several eV. A 100 keV X-ray can potentially create thousands of ions.

As discussed in Module 101, the distinction between X-rays and gamma rays is their origin, or method of production. Gamma rays originate from within the nucleus; X-rays originate from atomic electrons and from free electrons decelerating in the vicinity of atoms (i.e., bremsstrahlung).

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

C. X-RAY PRODUCTION

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

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

i. Bremsstrahlung.

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

i. Characteristic X-Rays.

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

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

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

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

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

i. Voltage.

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

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

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

ii. Current.

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

iii. Determining Electrical Power.

Power, which is measured in watts (W), equals voltage times current (P = V x I). For example, a 10 kVp device with a current of 1 mA uses 10 W of power.

(Insert facility-specific examples for determining electrical power.)

E. INTERACTION WITH MATTER

i. Scattering.

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

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

ii. Implications of Power and X-Ray Production.

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

$$P = V \times I$$

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

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

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

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

The percentage of the power transformed to X-rays can be estimated by the following relationship:

Fraction of incident electron energy transformed into X-ray energy equals:

$(7 \text{ X } 10^{-4}) \text{ x Z x E}$

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

In this case, the fraction would be:

$(7 \text{ X } 10^{-4}) \text{ x } 74 \text{ x } 0.150 = 0.008$

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

7500 W = 7500 J/s (*Note: 1 W = 1 J/s*)

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

1 J = 10^7 ergs, and 100 ergs/g = 1 rad.

So this X-ray energy represents:

$6.0 \text{ x } 10^8$ ergs/sec.

If all this X-ray energy were deposited in 1 g of tissue, the dose would be:
$6.0 \text{ x } 10^8$ ergs/sec [1 rad/100ergs/g] = $6.0 \text{ x } 10^6$ rad/sec.

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

iii. Filtration.

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

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

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

(Insert facility-specific examples of filtration.)

III. MODULE 103 - BIOLOGICAL EFFECTS

A. OBJECTIVES

i. Module Objective.

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

ii. Objectives.

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

1. Outline the early history of X-rays and the consequences of working with or around X-rays without protective measures.

2. Identify factors that determine the biological effects of X-ray exposure.

3. State the differences between thermal and X-ray burns.

4. Identify the signs and symptoms of an acute dose from X-rays.

5. Explain the effects of chronic exposure to X-rays.

6. Identify the difference between somatic and heritable effects.

B. EARLY HISTORY OF X-RAYS

i. Discovery of X-Rays.

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

By early February 1896, the first diagnostic X-ray in the United States was taken, followed quickly by the first X-ray picture of a fetus in utero. By March of that year, the first dental X-rays were taken. In that same month, French scientist Henri Becquerel was looking for fluorescence effects from the sun, using uranium on a photographic plate. The weather turned cloudy so he put the uranium and the photographic plate into a drawer. When Becquerel developed the plates a few weeks later, he realized he had made a new discovery. His student, Marie Curie, named it radioactivity.

ii. Discovery of Harmful Effects.

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

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

C. BIOLOGICAL EFFECTS OF IONIZATION (*Objective 3*)

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

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

D. FACTORS THAT DETERMINE BIOLOGICAL EFFECTS

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

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

i. Dose Rate.

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

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

ii. Total Dose Received.

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

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

iii. Energy of the Radiation.

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

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

iv. Area of the Body Exposed.

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

v. Individual Sensitivity.

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

vi. Cell Sensitivity.

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

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

It is generally accepted that cells tend to be radiosensitive if they are:
1) Cells that have a high division rate
2) Cells that have a high metabolic rate
3) Cells that are of a non-specialized type
4) Cells that are well nourished

The following are radiosensitive tissues:
1) Germinal
2) Hematopoietic
3) Epithelium of the skin
4) Epithelium of the gastrointestinal tract

The following are radioresistant tissues:
1) Bone
2) Liver
3) Kidney
4) Cartilage
5) Muscle
6) Nervous system tissue

E. SOMATIC EFFECTS

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

i. Early Acute Somatic Effects.

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

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

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

ii. Difference Between X-Ray Damage and Thermal Burns (Key Item) (*Objective 3*).

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

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

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

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

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

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

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

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

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

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

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

It does not take long to get a significant dose from an X-ray unit. The dose rate from an X-ray unit can be estimated from the Health Physics and Radiological Health Handbook, 1992 edition Table 10.1.1.

Example: Assume:
2.5 mm Al filter
100 kVp
100 mA
1 sec exposure
30 cm distance

Dose estimate (in air, assuming electron equilibrium): 12.8 Rad

(Compare these values to facility-specific equipment or examples.)

iv. Latent Effects from Radiation Exposure.

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

v. Risk of Developing Cancer from Low Doses (*Refer to BEIR V Report, NCRP 116, and ICRP60*).

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

However, below 10 rem, health effects are too small to measure. The dose limits and administrative control levels listed in Module 101 have been established so that the risk to workers is on a par with the risks to workers in safe industries, assuming a linear relationship between dose and health effects. However, these are maximum values and the ALARA principle stresses maintaining doses well below these values.

vi. Effects of Prenatal Exposure (Teratogenic Effects).

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

Workers who become pregnant are encouraged to declare their pregnancy in writing to their supervisors. (*10 CFR 835.206*) The dose limit for the embryo/fetus of a declared pregnant worker is 500 mrem during the term of the pregnancy; 10 CFR 835.206 (b) states "Substantial variation above a uniform exposure rate that would satisfy the limits provided in 10 CFR835.206 (a) [i.e., 500 mrem for term of pregnancy] shall be avoided."

F. HERITABLE EFFECTS

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

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

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

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

IV. MODULE 104 - RADIATION DETECTION

A. OBJECTIVES

i. Module Objective.

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

ii. Objectives.

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

1. Identify the instruments used for X-ray detection and
2. Identify the devices used for personnel monitoring.

B. RADIATION SURVEYS

Radiation protection surveys should be conducted on all new or newly installed X-ray devices by the X-Ray Device Control Office (or facility-specific equivalent) and repeated at a frequency determined by site policies.

C. X-RAY DETECTION INSTRUMENTS (*Objective 4*)

External exposure controls used to minimize the dose to workers are based on the data taken with portable radiation-monitoring instruments during a radiation survey. An understanding of these instruments is important to ensure that the data obtained are accurate and appropriate for the source of radiation. (*Note: Emphasize that completion of this training will <u>not</u> qualify individuals to use these instruments, specific instrument training is required*.)

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

- Selection of the appropriate instrument based on type and energy of radiation and on radiation intensity.

- Correct operation of the instrument based on the instrument operating characteristics and limitations.

- Calibration of the instrument to a known radiation field similar in type, energy, and intensity to the radiation field to be measured.

i. Instruments Used for X-Ray Detection

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

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

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

ii. Facility-Specific Instrumentation.

(Insert facility-specific information on instrumentation, as appropriate.)

D. PERSONNEL-MONITORING DEVICES

Note: X-ray leakage from RPD housings or shielding may be a narrow beam that is difficult to detect and may not be recorded by personnel monitoring devices.

i. Whole Body Dosimeters. (*Objective 2; 10 CFR 835.801(d)*)

Operators of intentional X-ray devices usually wear dosimetry such as thermoluminescent dosimeters (TLDs) film or badges. These dosimeters can accurately measure radiation doses as low as 10 mrem and are used to determine the dose of record. However, they must be sent to a processor to be read. Therefore, the exposed individual may not be aware of his exposure until the results have been reported (typically 1 day - several weeks).

There are several precautions that are important in the use of dosimeters. Dosimeters should be worn in a location that will record a dose representative of the trunk of the body. Standard practice is to wear a dosimeter between the neck and the waist, but in specific situations such as nonuniform radiation fields, special considerations may apply. Some dosimeters have a required orientation with a specific side facing out.

(Insert facility-specific information on dosimetry, as appropriate.)

ii. Extremity Dosimeters.

Finger-ring and wrist dosimeters may be used to assess radiation dose to the hands.

(Insert facility-specific information on dosimetry, as appropriate.)

iii. Pocket Dosimeters.

Pocket ionization chambers, such as pencil dosimeters or electronic dosimeters, are used in radiological work. In contrast to TLDs, they give an immediate readout of the radiation dose. Pencil dosimeters are manufactured with scales in several different ranges, but the 0B500 mR range, marked in increments of 20 mR, is often used. The dose is read by observing the position of a hairline that moves upscale in proportion to dose. Pocket dosimeters are supplemental and used primarily as radiological worker management tools. They are not typically used for determining the dose of record required by 10 CFR 835.

iv. Alarming Dosimeters.

In higher dose-rate areas, an alarming dosimeter may be used to provide an audible warning of radiation. This contributes to keeping doses ALARA by increasing a worker's awareness of the radiation.

Specific applications may require special considerations. For example, low-energy X-rays will not penetrate the walls of some dosimeters. Flash X-ray devices produce a very short pulse that is not correctly measured by most dose-rate instruments.

(Insert facility-specific information as appropriate.)

V. MODULE 105 - PROTECTIVE MEASURES

A. OBJECTIVES

i. Module Objective.

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

ii. Objectives.

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

1. Identify and state specific administrative and engineered controls.
2. Identify and state specific radiological postings.
3. Define "interlocks", as applicable.
4. Explain specific shielding practices.
5. Identify typical RPD warning devices.
6. Outline site-specific work documents.

B. RADIOLOGICAL CONTROLS (*Objective 6 10 CFR 835.501-502, 10 CFR 835.601-603, 10 CFR 835.1001-1003*)

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

Examples of administrative controls include:

- Posting.
- Warning signals and labels.
- Work control documents such as SOPs and RWPs.

Examples of engineered controls include:

- Interlocks.
- Shielding.

For high-radiation areas where radiation levels exist such that an individual could exceed an equivalent dose to the whole body of 1 rem in any 1 hour at 30 cm from the source or surface that the radiation penetrates, one or more of the following features shall be used to control exposure: (*10 CFR 835.502*)

- A control device that prevents entry.
- A device that prevents use of the radiation source while personnel are present.
- A device that energizes a visible and audible alarm.
- Locked entry ways.
- Continuous direct or electronic surveillance to prevent unauthorized entry.
- A device that generates audible and visual alarms in sufficient time to permit evacuation.

In addition to the above measures, for very high radiation areas (areas accessible to individuals in which radiation levels could result in an individual receiving a dose in excess of 500 rads in 1 hour), additional measures shall be implemented to ensure individuals are not able to gain access.

C. RADIOLOGICAL POSTINGS

i. Purpose of Posting.

The two primary reasons for radiological posting are:

1. To inform workers of the radiological conditions and

2. To inform workers of the entry requirements for an area.

ii. General Posting Requirements (*10 CFR 835.601(c)*).

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

2. Signs shall be clearly and conspicuously posted to alert personnel to the presence of radiation. Signs may also include radiological protection instructions. (*10 CFR 835.601(d)*)

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

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

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

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

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

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

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

   "CAUTION, RADIATION AREA." (*10 CFR 835.603(a)*)

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

"DANGER, HIGH RADIATION AREA." Or
"CAUTION, HIGH RADIATION AREA." (*10 CFR 835.603(b)*)

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

"GRAVE DANGER, VERY HIGH RADIATION AREA." (*10 CFR 835.603(c)*)

The same posting requirements apply for X-ray or gamma radiation as for any other type of radiation. Areas controlled for radiological purposes are posted according to the radiation dose rates in the area, as shown in the following table. These definitions are standard throughout the DOE complex.

Areas	**Defining Condition**
Controlled Area	Means any area to which access is managed to protect individuals from exposure to radiation and/or radioactive material.
Radiation Area	Means any area accessible to individuals in which radiation levels could result in an individual receiving an equivalent dose to the whole body in excess of 0.005 rem (0.05 millisievert) in 1 hour at 30 centimeters from the source or from any surface that the radiation penetrates.
High Radiation Area	Means any area accessible to individuals, in which radiation levels could result in an individual receiving an equivalent dose to the whole body in excess of 0.1 rem (0.001 sievert) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.
Very High Radiation Area	Means any area accessible to individuals in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rads (5 grays) in 1 hour at 1 meter from a radiation source or from any surface that the radiation penetrates.

(Insert facility-specific information on posting, labeling, and entry requirements, as applicable.)

D. INTERLOCKS

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

Guidance from the ANSI standards is that interlocks should be tested by the operating group at least every six months. (*Refer to ANSI N43.2*) The interlock test procedure may be locally specified, but typically is as follows:

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

(Insert facility-specific information, as appropriate.)

E. SHIELDING

i. Analytical Systems.

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

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

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

ii. Industrial Systems.

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

X-Ray Device Control Office (or facility-specific equivalent) personnel develop recommendations for shielding based on the following information:

1. Shielding the primary X-ray beam and
2. Shielding the areas not in the line of the primary beam from leakage and scattered radiation.

There are independent analyses for each component to derive an acceptable shield thickness.

For example, the calculation used for the primary X-ray beam depends on:

- Peak voltage.
- The maximum permissible exposure rate to an individual.
- The workload of the machine expressed in mA min/wk.
- The use factor: the fraction of the workload during which the useful beam is pointed in a direction under consideration.
- The occupancy factor that takes into account the fraction of time that an area outside the barrier is likely to be occupied by a given individual.
- The distance from the target of the tube to the location under consideration.

The calculation uses conservative values and derives a value (K) that is used with graphs to determine shield thickness of a given type of material (e.g., lead or concrete).

F. WARNING DEVICES

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

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

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

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

G. WORK DOCUMENTS

(Note: this section is provided only as an example and should be replaced with facility-specific information.) (*Objective 6*)

i. Typical Standard Operating Procedures (SOP).

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

1. Description/specification of the X-ray device and the purpose for which it is used.

2. Normal X-ray parameters (peak power, current, exposure time, X-ray source-to-film distance, etc.).

3. Procedures for proper sample preparation, alignment procedures, or handling of object to be radiographed.

4. Description of all safety hazards (electrical, mechanical, explosive, as well as radiation hazards) associated with the operation of the X-ray device.

5. Description of the safety features such as interlocks and warning signals and any other safety precautions.

6. Procedures for performing interlock tests and the recommended frequency of such tests.
7. Required operator training and dosimetry.
8. Posting of signs and labels.
9. X-ray device safety checklist (items to be checked periodically or each day before use).
10. Actions to take in the event of an abnormal occurrence or emergency.
11. Requirements for the use of a radiation-monitoring instrument upon entry into the Radiation Area to verify that the X-ray beam is off are specified in ANSI N43.3 for some industrial X-ray devices. (*Specify which types of X-ray devices require this measure at your facility (e.g., only open systems)).*
12. Key control responsibilities and use for key actuated devices.
13. Operator responsibility to ensure an energized machine is not left unattended.
14. Responsibility to check area and ensure accountability before actuation.
15. Operator prohibition against modifying the device or removing installed shielding.

X-Ray Device Control Office personnel (or facility-specific equivalent) review each SOP to verify that it establishes appropriate safety practices and they can assist the operating groups in preparing or modifying an SOP. The current SOP should be kept near the X-ray device.

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

ii. Radiological Work Permits (RWPs).

RWPs are used to establish radiological controls for entry into radiological areas. They serve to:

1. Inform workers of area radiological conditions.

2. Inform workers of entry requirements into the areas.

3. Provide a means to relate radiation doses to specific work activities.

A job-specific RWP is used to control nonroutine operations or work areas with changing radiological conditions.

RWPs are typically used in conjunction with X-ray devices when any of the following situations exist:

1. A compliance label for a newly acquired X-ray device cannot be issued because the SOP for that device has not yet been written and approved.

2. A portable X-ray device or open system used only for a short period that does not warrant writing an SOP.

3. An event that requires an operator enter the area when the X-ray beam is on. (*An example of a non-routine entry is one that requires operator entry with the beam on, creating a radiation area or high radiation area. Include facility-specific examples*.)

VI. MODULE 106 - X-RAY GENERATING DEVICES

A. OBJECTIVES

i. Module Objective.

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

(Note: Module 106 reflects the guidance of the ANSI Standards N43.2 and N43.3. Insert facility-specific information as appropriate.)

ii. Objectives.

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

1. Contrast incidental and intentional X-ray devices.
2. Contrast analytical and industrial X-ray devices.
3. Identify open and enclosed beam installations.
4. Describe the safety features essential for operation of industrial and analytical systems.

B. INCIDENTAL AND INTENTIONAL DEVICES (*Objective 7*)

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

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

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

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

C. INCIDENTAL X-RAY DEVICES

i. Exempt Shielded Systems.

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

(Add facility-specific examples.)

ii. Other Devices.

At a research laboratory, many devices produce incidental X-rays. Any device that combines high voltage and a vacuum could, in principle, produce X-rays. For example, a television or computer monitor generates incidental X-rays, but in modern designs the intensity is small, much less than 0.5 mrem/hour.

Occasionally, this hazard is recognized only after the device has operated for some time. If the participants suspect an X-ray hazard, contact an RCT or the X-Ray Device Control Office (or facility-specific equivalent) to survey the device.

(Add facility-specific examples.)

D. INTENTIONAL ANALYTICAL X-RAY DEVICES

i. Analytical X-Ray Devices.

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

The following safety features are common to both systems:

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

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

3. Shielding is provided.

(Add facility-specific examples.)

ii. Enclosed-Beam System.

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

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

1. The sample chamber door or other enclosure should have a fail-safe interlock on the X-ray tube high-voltage supply or a shutter in the primary beam so that no X-ray beam can enter the sample chamber while it is open.

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

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

(Add facility-specific examples.)

iii. Open-Beam System.

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

1. A need for frequent changes of attachments and configurations.

2. A need for making adjustments with the X-ray beam energized.

3. Motion of specimen and detector over wide angular limits.

4. The examination of large or bulky samples.

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

1. Each port of the X-ray tube housing must have a beam shutter.

2. All shutters must have a conspicuous SHUTTER OPEN indicator of fail-safe design.

3. Shutters at unused ports should be mechanically or electrically secured to prevent casual opening.

4. Special rules apply when the accessory setup is subject to change as is the case with powder diffraction cameras. In these cases, the beam shutter must be interlocked so the port will be open only when the accessory is in place.

5. Exposure rates adjacent to the system must not exceed 2.5 mrem/hour at 5 cm from the surface of the housing.

6. A guard or interlock must prevent entry of any part of the body into the primary beam.

(Insert facility-specific information if system definitions differ from the above.)

E. INTENTIONAL INDUSTRIAL X-RAY DEVICES

i. Industrial X-Ray Devices.

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

ii. Cabinet X-ray Installation.

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

(Add facility-specific examples.)

iii. Exempt Shielded Installation.

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

(Add facility-specific examples.)

iv. Shielded Installation.

A shielded installation has less shielding than exempt shielded. This is a cost advantage for fixed installations, particularly for high-energy sources where the reduction in shielding may result in significant savings. However, there is more reliance on protective measures such as warning lights, posting, and procedures. However, the posting and access control requirements, of 10 CFR 835 apply. Any High Radiation Area must be appropriately controlled and any Radiation Area must be defined and posted.
(Add facility-specific examples.)

v. Unattended Installation.

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

vi. Open Installation.

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

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

(Add facility-specific examples.)

F. SUMMARY OF X-RAY DEVICES

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

SUMMARY OF X-RAY DEVICES

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

VII. MODULE 107 - RESPONSIBILITIES FOR X-RAY SAFETY

A. OBJECTIVES

i. Module Objective.

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

ii. Objectives.

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

1. State the responsibilities of the X-Ray Device Control Office.
2. State the responsibilities of operating groups regarding X-ray safety.
3. State the responsibilities of X-ray device custodians.
4. State the responsibilities of X-ray device operators.

(Note: Module 107 is included as an example. Insert facility-specific information as appropriate.)

B. RESPONSIBILITIES

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

i. X-Ray Device Control Office. (*Objective 8*)

The X-Ray Device Control Office is responsible for:

1. Establishing requirements and standards.
2. Offering consulting services and training.
3. Approving purchases, moves, transfers, and alterations of X-ray equipment.
4. Surveying new equipment, verifying that the appropriate safety program requirements have been met, and affixing compliance labels to the devices.
5. Issuing variances for devices that do not meet one or more of the requirements, if safety is achieved through alternative means or if the function could not be performed if the device met the requirements.

ii. Operating Groups.

Operating groups are responsible for:

1. Complying with all X-ray safety requirements.
2. Registering X-ray machines.
3. Preparing SOPs.
4. Appointing X-ray device custodians.

5. Ensuring proper training of operators.

iii. X-Ray Device Custodians.

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

1. Completing X-Ray-Generating Device Registration forms and submitting them to the X-Ray Device Control Office to register new electron microscopes, intentional X-ray devices, and new X-ray tube assemblies or source housings.

2. Making arrangements for operator training.

3. Maintaining a list of qualified operators authorized for particular machines.

4. Documenting that operators have read the appropriate SOPs and machine safety features.

5. Posting an authorized operator list near the control panel of each X-ray device.

6. Checking enclosure door safety interlocks every six months to ensure proper functioning and recording results on an interlock test log posted on or near the control panel.

7. Contacting the X-Ray Device Control Office before performing any repair, maintenance, and/or nonroutine work that could cause the exposure of any portion of the body to the primary beam.

8. Meeting all requirements of Safe Operating Procedures, Special Work Permits, and Lockout/Tagout for Control of Hazardous Energy Sources for Personnel Safety (Red Lock Procedure).

iv. X-Ray Device Operators.

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

1. Wearing a TLD badge.

2. Knowing the SOP for every machine operated.

3. Notifying his/her supervisor of any unsafe or hazardous work situations.

4. Before reaching into the primary beam, verifying that the beam shutter is closed or that machine power is off.

5. Meeting all applicable training requirements before operating RPD.

6. Maintaining exposures ALARA.

GLOSSARY

Terms used consistent with their regulatory meaning.

Accelerator: A device employing electrostatic or electromagnetic fields to impart kinetic energy to molecular, atomic, or subatomic particles and capable of creating a radiological area (DOE Order 5480.25).

Examples include linear accelerators, cyclotrons, synchrotrons, synchrocyclotrons, free-electron lasers (FELs), and ion LINACs. Single and tandem Van de Graaff generators, when used to accelerate charged particles *other than electrons*, are also considered accelerators. Specifically *excluded* from this definition (per DOE 0 5480.25) are the following:

- Unmodified commercially available units such as electron microscopes, ion implant devices, and X-ray generators that are acceptable for industrial applications.

- Accelerator facilities not capable of creating a radiological area.

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

Access port: *See* port.

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

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

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

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

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

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

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

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

Compliance label: A label affixed to an intentional X-ray device certifying that the device has been surveyed and that safe operating requirements have been met.

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

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

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

Dosimeter: A device that measures and indicates radiation dose.

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

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

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

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

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

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

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

Floor: In this context, the underside external surface of the cabinet.

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

Gauge: A device that produces ionizing radiation for the purpose of measuring particular properties of a system.

Half-value layer (HVL): The thickness of a specified substance that, when introduced into a beam of radiation, reduces the dose rate by one-half.

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

Installation: A radiation source, with its associated equipment, and the space in which it is located.

Installation enclosure: The portion of an X-ray installation that clearly defines the transition from a noncontrolled to a controlled area and provides such shielding as may be required to limit the dose rate in the noncontrolled area during normal operations.

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

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

Ion: An atom, or molecule bearing an electric charge, or an electron that is not associated with a nucleus.

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

Lead equivalent: The thickness of lead affording the same attenuation, under specific conditions, as the shielding material in use.

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

Medical X-ray system: An X-ray system for medical use, generally categorized as either diagnostic or therapeutic. Diagnostic X-ray procedures are used to obtain images of body parts; therapeutic x-ray procedures are used to manage malignancies.

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

Occupancy factor: The factor by which the workload should be multiplied to correct for the degree or type of occupancy of the area specified.

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

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

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

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

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

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

Radiation source: A device or a material that is capable of emitting ionizing radiation.

Radiological control technician (RCT): Any person who is actively engaged in or who has completed facility-specific RCT training and qualification programs.

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

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

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

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

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

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

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

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

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

System barrier: The portion of an X-ray installation that clearly defines the transition from a Controlled Area to a Radiation Area and provides such shielding as may be required to limit the dose rate in the Controlled Area during normal operation.

Tenth-value layer (TVL): The thickness of a specified substance that, when introduced into a beam of radiation, reduces the dose rate to one-tenth of the original value. One TVL is equivalent to 3.3 HVLs.

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

Use factor: The fraction of the workload during which the useful beam is pointed in the direction under consideration.

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

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

Workload: A measure, in suitable units, of the amount of use of radiation equipment. For the purpose of this standard, the workload is expressed in milliampere-minutes per week for X-ray sources and in roentgens per week at 1 meter from the source for gamma-ray sources and high-energy equipment (such as linear accelerators, betatrons, etc.).

X-ray accessory apparatus: Any portion of an X-ray installation that is external to the radiation source housing and into which an X-ray beam is directed for making X-ray measurements or for other uses.

X-Ray Device Control Office: A team that establishes X-ray device program requirements and standards, provides X-ray device radiation protection consultation, and serves as the central point of contact for the management/control of X-ray devices. This function may have a facility-specific name.

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

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

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

X-ray installation: One or more X-ray systems, the surrounding room or controlled area, and the installation enclosure.

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

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

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

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

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

Part 3 of 3

Student's Guide

Radiological Safety Training
for Radiation-Producing (X-Ray) Devices

Coordinated and Conducted

for

Office of Health, Safety and Security

U.S. Department of Energy

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TERMINAL OBJECTIVE:

Demonstrate a basic understanding of :

- General radiation protection principles for safe operation of X-ray devices.

ENABLING OBJECTIVES:

When the participants have completed this course, the participants will be able to:

EO1	Describe ionizing radiation.
EO2	Describe what X-rays are, how they are generated, and how they interact with matter.
EO3	Describe the biological effects of X-rays.
EO4	Identify and describe radiation-monitoring instruments and personnel-monitoring devices appropriate for detecting X-rays.
EO5	Demonstrate a familiarity with DOE dose limits, facility-specific administrative controls, ALARA, and the major methods for controlling and minimizing external exposure.
EO6	Identify and describe protective measures that restrict or control access to X-ray areas and devices, and warn of X-ray hazards; and be able to identify and describe work documents that provide specific procedures to ensure safe operation of X-ray devices.
EO7	Identify and describe the categories of X-ray-producing devices.
EO8	Explain who is responsible for implementing X-ray safety policies and procedures and describe their specific responsibilities.
EO9	Identify causes of accidental exposures.

I. MODULE 101 - RADIATION PROTECTION PRINCIPLES

A. OBJECTIVES

i. Module Objective.

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

ii. Objectives.

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

1. Define ionizing radiation.
2. Identify sources of natural and manmade background radiation.
3. Define the DOE dose limits and facility-specific administrative control levels.
4. Describe the ALARA principle.
5. List the three major methods by which external exposure is reduced.

B. ATOMS

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

C. IONIZATION

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

D. RADIATION

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

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

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

X-rays and gamma rays are a form of electromagnetic radiation. X-rays differ from gamma rays in their point of origin. Gamma rays originate from within the atomic nucleus, whereas X-rays originate from the electrons outside the nucleus and from free electrons decelerating in the vicinity of atoms (i.e., bremsstrahlung). Module 102 discusses how X-rays are produced.

E. UNITS

- Roentgen (R), a measure of radiation *exposure*, is defined by ionization in air by x or gamma radiation.

- Rad, a measure of the energy absorbed per unit mass. It is defined for any absorbing material.

- Rem, a unit of equivalent dose, which is the energy absorbed per unit mass times the applicable radiation weighting factor and other modifying factors.

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

F. BACKGROUND RADIATION

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

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

The equivalent dose to the whole body (i.e., at a depth of 1 cm in tissue) from a chest X-ray is 5 - 10 mrem, a dental X-ray is 50 - 300 mrem, and mammography is 0.5 - 2 rem.

G. DOSE LIMITS

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

The following table lists both DOE dose limits and administrative control levels. Administrative control levels are established lower than the DOE limits to ensure that doses are kept below the DOE limits.

DOE Dose Limits and Facility-Specific Administrative Control Levels		
	DOE Dose Limits	Facility-Specific Administrative Control Levels
whole body total effective dose	5 rem/year	insert facility-specific value
extremity	50 rem/year	insert facility-specific value
skin	50 rem/year	insert facility-specific value
internal organ committed equivalent dose	50 rem/year	insert facility-specific value
lens of the eye	15 rem/year	insert facility-specific value
embryo/fetus	0.5 rem/term of pregnancy (for the embryo/fetus of workers who declare pregnancy)	insert facility-specific value
minors and public	0.1 rem/year	insert facility-specific value

DOE facilities are designed and operated to reduce personnel doses as far below the occupational limits as reasonably achievable. The dose received by DOE X-ray workers is typically between 0 and 100 mrem per year above the natural background.

H. CAUSES OF ACCIDENTAL EXPOSURES (KEY ITEM)

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

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

Every year there are numerous X-ray incidents nationwide. Of these, about one third result in injury to a person. The incident rate at DOE laboratories is much lower than the national average.

I. ALARA

Because the effects of chronic doses of low levels of ionizing radiation are not precisely known, we assume there is some risk for any dose. The ALARA principle is to keep radiation dose *as low as reasonably achievable*, considering economic and social constraints.

The goal of an ALARA Program is to keep radiation dose as far below the occupational dose limits and administrative control levels as is reasonably achievable. The success of an ALARA Program is directly linked to a clear understanding and following of the policies and procedures for the protection of workers. Keeping radiation dose ALARA is the responsibility of all workers, management, and the radiation-protection organization.

J. REDUCING EXTERNAL DOSE (KEY ITEM)

Three basic ways to reduce external doses are to

- Minimize time.
- Maximize distance.
- Use shielding.

Minimize time near a source of radiation by planning ahead. Increase distance by moving away from the source of radiation whenever possible. The dose from X-ray sources is inversely proportional to the square of the distance. This is called the inverse square law, that is, when the distance is doubled, the dose is reduced to one-fourth of the original value. Proper facility design uses the amount and type of shielding appropriate for the radiation hazard. Lead, concrete, and steel are effective in shielding against X-rays.

II. MODULE 102 - PRODUCTION OF X-RAYS

A. OBJECTIVES

i. Module Objective.

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

ii. Objectives.

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

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

B. ELECTROMAGNETIC RADIATION

i. Types of Electromagnetic Radiation.

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

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

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

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

ii. X-Rays and Gamma Rays.

X-rays and gamma rays both ionize atoms. The energy required for ionization varies with material (e.g., 34 eV in air, 25 eV in tissue) but is generally in the range of several eV. A 100 keV X-ray can potentially create thousands of ions.

As discussed in Module 101, the distinction between X-rays and gamma rays is their origin, or method of production. Gamma rays originate from within the nucleus; X-rays originate from atomic electrons and from free electrons decelerating in the vicinity of atoms (i.e., bremsstrahlung).

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

C. X-RAY PRODUCTION

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

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

i. Bremsstrahlung.

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

i. Characteristic X-Rays.

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

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

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

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

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

i. Voltage.

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

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

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

ii. Current.

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

iii. Determining Electrical Power.

Power, which is measured in watts (W), equals voltage times current ($P = V \times I$). For example, a 10 kVp device with a current of 1 mA uses 10 W of power.

(Insert facility-specific examples for determining electrical power.)

E. INTERACTION WITH MATTER

i. Scattering.

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

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

ii. Implications of Power and X-Ray Production.

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

$$P = V \times I$$

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

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

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

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

The percentage of the power transformed to X-rays can be estimated by the following relationship:

Fraction of incident electron energy transformed into X-ray energy equals:

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

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

In this case, the fraction would be:

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

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

7500 W = 7500 J/s

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

1 J = 10^7 ergs, and 100 ergs/g = 1 rad.

So this X-ray energy represents:

6.0×10^8 ergs/sec.
If all this X-ray energy were deposited in 1 g of tissue, the dose would be:
6.0×10^8 ergs/sec [1 rad/100ergs/g] =
6.0×10^6 rad/sec.

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

iii. Filtration.

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

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

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

(Insert facility-specific examples of filtration.)

III. MODULE 103 - BIOLOGICAL EFFECTS

A. OBJECTIVES

i. Module Objective.

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

ii. Objectives.

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

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

B. EARLY HISTORY OF X-RAYS

i. Discovery of X-Rays.

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

By early February 1896, the first diagnostic X-ray in the United States was taken, followed quickly by the first X-ray picture of a fetus in utero. By March of that year, the first dental X-rays were taken. In that same month, French scientist Henri Becquerel was looking for fluorescence effects from the sun, using uranium on a photographic plate. The weather turned cloudy so he put the uranium and the photographic plate into a drawer. When Becquerel developed the plates a few weeks later, he realized he had made a new discovery. His student, Marie Curie, named it radioactivity.

ii. Discovery of Harmful Effects.

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

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

C. BIOLOGICAL EFFECTS OF IONIZATION

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

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

D. FACTORS THAT DETERMINE BIOLOGICAL EFFECTS

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

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

i. Dose Rate.

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

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

ii. Total Dose Received.

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

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

iii. Energy of the Radiation.

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

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

iv. Area of the Body Exposed.

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

v. Individual Sensitivity.

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

vi. Cell Sensitivity.

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

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

It is generally accepted that cells tend to be radiosensitive if they are:
1) Cells that have a high division rate
2) Cells that have a high metabolic rate
3) Cells that are of a non-specialized type
4) Cells that are well nourished

The following are radiosensitive tissues:
1) Germinal
2) Hematopoietic
3) Epithelium of the skin
4) Epithelium of the gastrointestinal tract

The following are radioresistant tissues:
1) Bone
2) Liver
3) Kidney
4) Cartilage
5) Muscle
6) Nervous system tissue

E. SOMATIC EFFECTS

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

i. Early Acute Somatic Effects.

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

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

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

ii. Difference Between X-Ray Damage and Thermal Burns (Key Item).

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

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

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

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

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

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

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

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

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

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

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

It does not take long to get a significant dose from an X-ray unit. The dose rate from an X-ray unit can be estimated from the Health Physics and Radiological Health Handbook, 1992 edition Table 10.1.1.

Example: Assume:
2.5 mm Al filter
100 kVp
100 mA
1 sec exposure
30 cm distance

Dose estimate (in air, assuming electron equilibrium): 12.8 Rad

(Compare these values to facility-specific equipment or examples.)

iv. Latent Effects from Radiation Exposure.

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

v. Risk of Developing Cancer from Low Doses.

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

However, below 10 rem, health effects are too small to measure. The dose limits and administrative control levels listed in Module 101 have been established so that the risk to workers is on a par with the risks to workers in safe industries, assuming a linear relationship between dose and health effects. However, these are maximum values and the ALARA principle stresses maintaining doses well below these values.

vi. Effects of Prenatal Exposure (Teratogenic Effects).

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

Workers who become pregnant are <u>encouraged to declare their pregnancy in writing</u> to their supervisors. The dose limit for the embryo/fetus of a declared pregnant worker is

500 mrem during the term of the pregnancy; 10 CFR 835.206 (b) states "Substantial variation above a uniform exposure rate that would satisfy the limits provided in 10 CFR835.206 (a) [i.e., 500 mrem for term of pregnancy] shall be avoided."

F. HERITABLE EFFECTS

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

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

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

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

IV. MODULE 104 - RADIATION DETECTION

A. OBJECTIVES

i. Module Objective.

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

ii. Objectives.

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

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

2. Identify the devices used for personnel monitoring.

B. RADIATION SURVEYS

Radiation protection surveys should be conducted on all new or newly installed X-ray devices by the X-Ray Device Control Office (or facility-specific equivalent) and repeated at a frequency determined by site policies.

C. X-RAY DETECTION INSTRUMENTS

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

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

- Selection of the appropriate instrument based on type and energy of radiation and on radiation intensity.

- Correct operation of the instrument based on the instrument operating characteristics and limitations.

- Calibration of the instrument to a known radiation field similar in type, energy, and intensity to the radiation field to be measured.

i. Instruments Used for X-Ray Detection

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

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

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

ii. Facility-Specific Instrumentation.

(Insert facility-specific information on instrumentation, as appropriate.)

D. PERSONNEL-MONITORING DEVICES

Note: X-ray leakage from RPD housings or shielding may be a narrow beam that is difficult to detect and may not be recorded by personnel monitoring devices.

i. Whole Body Dosimeters.

Operators of intentional X-ray devices usually wear dosimetry such as thermoluminescent dosimeters (TLDs) film or badges. These dosimeters can accurately measure radiation doses as low as 10 mrem and are used to determine the dose of record. However, they must be sent to a processor to be read. Therefore, the exposed individual may not be aware of his exposure until the results have been reported (typically 1 day - several weeks).

There are several precautions that are important in the use of dosimeters. Dosimeters should be worn in a location that will record a dose representative of the trunk of the body. Standard practice is to wear a dosimeter between the neck and the waist, but in specific situations such as nonuniform radiation fields, special considerations may apply. Some dosimeters have a required orientation with a specific side facing out.

(Insert facility-specific information on dosimetry, as appropriate.)

ii. Extremity Dosimeters.

Finger-ring and wrist dosimeters may be used to assess radiation dose to the hands.

(Insert facility-specific information on dosimetry, as appropriate.)

iii. Pocket Dosimeters.

Pocket ionization chambers, such as pencil dosimeters or electronic dosimeters, are used in radiological work. In contrast to TLDs, they give an immediate readout of the radiation dose. Pencil dosimeters are manufactured with scales in several different ranges, but the 0B500 mR range, marked in increments of 20 mR, is often used. The dose is read by observing the position of a hairline that moves upscale in proportion to dose. Pocket dosimeters are supplemental and used primarily as radiological worker management tools. They are not typically used for determining the dose of record required by 10 CFR 835.

iv. Alarming Dosimeters.

In higher dose-rate areas, an alarming dosimeter may be used to provide an audible warning of radiation. This contributes to keeping doses ALARA by increasing a worker's awareness of the radiation.

Specific applications may require special considerations. For example, low-energy X-rays will not penetrate the walls of some dosimeters. Flash X-ray devices produce a very short pulse that is not correctly measured by most dose-rate instruments.

(Insert facility-specific information as appropriate.)

V. MODULE 105 - PROTECTIVE MEASURES (Entire Module - Key Item)

A. OBJECTIVES

i. Module Objective.

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

ii. Objectives.

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

1. Identify and state specific administrative and engineered controls.

2. Identify and state specific radiological postings.

3. Define "interlocks", as applicable.

4. Explain specific shielding practices.

5. Identify typical RPD warning devices.

6. Outline site-specific work documents.

B. RADIOLOGICAL CONTROLS

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

Examples of administrative controls include:

- Posting.
- Warning signals and labels.
- Work control documents such as SOPs and RWPs.

Examples of engineered controls include:

- Interlocks.
- Shielding.

For high-radiation areas where radiation levels exist such that an individual could exceed an equivalent dose to the whole body of 1 rem in any 1 hour at 30 cm from the source or surface that the radiation penetrates, one or more of the following features shall be used to control exposure:

- A control device that prevents entry.
- A device that prevents use of the radiation source while personnel are present.
- A device that energizes a visible and audible alarm.
- Locked entry ways.
- Continuous direct or electronic surveillance to prevent unauthorized entry.
- A device that generates audible and visual alarms in sufficient time to permit evacuation.

In addition to the above measures, for very high radiation areas (areas accessible to individuals in which radiation levels could result in an individual receiving a dose in excess of 500 rads in 1 hour), additional measures shall be implemented to ensure individuals are not able to gain access.

C. RADIOLOGICAL POSTINGS

i. Purpose of Posting.

The two primary reasons for radiological posting are:

1. To inform workers of the radiological conditions and

2. To inform workers of the entry requirements for an area.

ii. General Posting Requirements.

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

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

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

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

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

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

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

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

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

   "CAUTION, RADIATION AREA."
   For a High Radiation Area, wording on the posting shall include the words:

   "DANGER, HIGH RADIATION AREA." Or
   "CAUTION, HIGH RADIATION AREA."

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

"GRAVE DANGER, VERY HIGH RADIATION AREA."

The same posting requirements apply for X-ray or gamma radiation as for any other type of radiation. Areas controlled for radiological purposes are posted according to the radiation dose rates in the area, as shown in the following table. These definitions are standard throughout the DOE complex.

Areas	Defining Condition
Controlled Area	Means any area to which access is managed to protect individuals from exposure to radiation and/or radioactive material.
Radiation Area	Means any area accessible to individuals in which radiation levels could result in an individual receiving an equivalent dose to the whole body in excess of 0.005 rem (0.05 millisievert) in 1 hour at 30 centimeters from the source or from any surface that the radiation penetrates.
High Radiation Area	Means any area accessible to individuals, in which radiation levels could result in an individual receiving an equivalent dose to the whole body in excess of 0.1 rem (0.001 sievert) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.
Very High Radiation Area	Means any area accessible to individuals in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rads (5 grays) in 1 hour at 1 meter from a radiation source or from any surface that the radiation penetrates.

(Insert facility-specific information on posting, labeling, and entry requirements, as applicable.)

D. INTERLOCKS

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

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

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

(Insert facility-specific information, as appropriate.)

E. SHIELDING

i. Analytical Systems.

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

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

Minimum Shielding to Keep the Dose Rate Below 0.25 mrem/hour			
Anode Current	Millimeters of Lead		
(mA)	50 kVp	70 kVp	100 kVp
20	1.5	5.6	7.7
40	1.6	5.8	7.9
80	1.6	5.9	--
160	1.7	--	--

ii. Industrial Systems.

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

X-Ray Device Control Office (or facility-specific equivalent) personnel develop recommendations for shielding based on the following information:

1. Shielding the primary X-ray beam and
2. Shielding the areas not in the line of the primary beam from leakage and scattered radiation.

There are independent analyses for each component to derive an acceptable shield thickness.

For example, the calculation used for the primary X-ray beam depends on:

- Peak voltage.
- The maximum permissible exposure rate to an individual.
- The workload of the machine expressed in mA min/wk.
- The use factor: the fraction of the workload during which the useful beam is pointed in a direction under consideration.
- The occupancy factor that takes into account the fraction of time that an area outside the barrier is likely to be occupied by a given individual.
- The distance from the target of the tube to the location under consideration.

The calculation uses conservative values and derives a value (K) that is used with graphs to determine shield thickness of a given type of material (e.g., lead or concrete).

F. WARNING DEVICES

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

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

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

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

G. WORK DOCUMENTS

(Note: this section is provided only as an example and should be replaced with facility-specific information.)

i. Typical Standard Operating Procedures (SOP).

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

1. Description/specification of the X-ray device and the purpose for which it is used.
2. Normal X-ray parameters (peak power, current, exposure time, X-ray source-to-film distance, etc.).
3. Procedures for proper sample preparation, alignment procedures, or handling of object to be radiographed.
4. Description of all safety hazards (electrical, mechanical, explosive, as well as radiation hazards) associated with the operation of the X-ray device.
5. Description of the safety features such as interlocks and warning signals and any other safety precautions.
6. Procedures for performing interlock tests and the recommended frequency of such tests.
7. Required operator training and dosimetry.
8. Posting of signs and labels.
9. X-ray device safety checklist (items to be checked periodically or each day before use).

10. Actions to take in the event of an abnormal occurrence or emergency.
11. Requirements for the use of a radiation-monitoring instrument upon entry into the Radiation Area to verify that the X-ray beam is off are specified in ANSI N43.3 for some industrial X-ray devices.
12. Key control responsibilities and use for key actuated devices.
13. Operator responsibility to ensure an energized machine is not left unattended.
14. Responsibility to check area and ensure accountability before actuation.
15. Operator prohibition against modifying the device or removing installed shielding.

X-Ray Device Control Office personnel (or facility-specific equivalent) review each SOP to verify that it establishes appropriate safety practices and they can assist the operating groups in preparing or modifying an SOP. The current SOP should be kept near the X-ray device.

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

ii. Radiological Work Permits (RWPs).

RWPs are used to establish radiological controls for entry into radiological areas. They serve to:

1. Inform workers of area radiological conditions.

2. Inform workers of entry requirements into the areas.

3. Provide a means to relate radiation doses to specific work activities.

A job-specific RWP is used to control nonroutine operations or work areas with changing radiological conditions.

RWPs are typically used in conjunction with X-ray devices when any of the following situations exist:

1. A compliance label for a newly acquired X-ray device cannot be issued because the SOP for that device has not yet been written and approved.

2. A portable X-ray device or open system used only for a short period that does not warrant writing an SOP.

3. An event that requires an operator enter the area when the X-ray beam is on.

VI. MODULE 106 - X-RAY GENERATING DEVICES

A. OBJECTIVES

i. Module Objective.

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

(Note: Module 106 reflects the guidance of the ANSI Standards N43.2 and N43.3. Insert facility-specific information as appropriate.)

ii. Objectives.

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

1. Contrast incidental and intentional X-ray devices.
2. Contrast analytical and industrial X-ray devices.
3. Identify open and enclosed beam installations.
4. Describe the safety features essential for operation of industrial and analytical systems.

B. INCIDENTAL AND INTENTIONAL DEVICES

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

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

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

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

C. INCIDENTAL X-RAY DEVICES

i. Exempt Shielded Systems.

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

(Add facility-specific examples.)

ii. Other Devices.

At a research laboratory, many devices produce incidental X-rays. Any device that combines high voltage and a vacuum could, in principle, produce X-rays. For example, a television or computer monitor generates incidental X-rays, but in modern designs the intensity is small, much less than 0.5 mrem/hour.

Occasionally, this hazard is recognized only after the device has operated for some time. If the participants suspect an X-ray hazard, contact an RCT or the X-Ray Device Control Office (or facility-specific equivalent) to survey the device.

(Add facility-specific examples.)

D. INTENTIONAL ANALYTICAL X-RAY DEVICES

i. Analytical X-Ray Devices.

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

The following safety features are common to both systems:

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

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

3. Shielding is provided.

(Add facility-specific examples.)

ii. Enclosed-Beam System.

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

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

1. The sample chamber door or other enclosure should have a fail-safe interlock on the X-ray tube high-voltage supply or a shutter in the primary beam so that no X-ray beam can enter the sample chamber while it is open.

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

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

(Add facility-specific examples.)

iii. Open-Beam System.

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

1. A need for frequent changes of attachments and configurations.

2. A need for making adjustments with the X-ray beam energized.

3. Motion of specimen and detector over wide angular limits.

4. The examination of large or bulky samples.

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

1. Each port of the X-ray tube housing must have a beam shutter.

2. All shutters must have a conspicuous SHUTTER OPEN indicator of fail-safe design.

3. Shutters at unused ports should be mechanically or electrically secured to prevent casual opening.

4. Special rules apply when the accessory setup is subject to change as is the case with powder diffraction cameras. In these cases, the beam shutter must be interlocked so the port will be open only when the accessory is in place.

5. Exposure rates adjacent to the system must not exceed 2.5 mrem/hour at 5cm from the surface of the housing.

6. A guard or interlock must prevent entry of any part of the body into the primary beam.

(Insert facility-specific information if system definitions differ from the above.)

E. INTENTIONAL INDUSTRIAL X-RAY DEVICES

i. Industrial X-Ray Devices.

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

ii. Cabinet X-ray Installation.

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

(Add facility-specific examples.)

iii. Exempt Shielded Installation.

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

(Add facility-specific examples.)

iv. Shielded Installation.

A shielded installation has less shielding than exempt shielded. This is a cost advantage for fixed installations, particularly for high-energy sources where the reduction in shielding may result in significant savings. However, there is more reliance on protective measures such as warning lights, posting, and procedures. However, the posting and access control requirements, of 10 CFR 835 apply. Any High Radiation Area must be appropriately controlled and any Radiation Area must be defined and posted.

(Add facility-specific examples.)

v. Unattended Installation.

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

vi. Open Installation.

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

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

(Add facility-specific examples.)

F. SUMMARY OF X-RAY DEVICES

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

SUMMARY OF X-RAY DEVICES

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

VII. MODULE 107 - RESPONSIBILITIES FOR X-RAY SAFETY

A. OBJECTIVES

i. Module Objective.

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

ii. Objectives.

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

1. State the responsibilities of the X-Ray Device Control Office.

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

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

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

(Note: Module 107 is included as an example. Insert facility-specific information as appropriate.)

B. RESPONSIBILITIES

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

i. X-Ray Device Control Office.

The X-Ray Device Control Office is responsible for:

1. Establishing requirements and standards.

2. Offering consulting services and training.

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

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

5. Issuing variances for devices that do not meet one or more of the requirements, if safety is achieved through alternative means or if the function could not be performed if the device met the requirements.

ii. Operating Groups.

Operating groups are responsible for:

1. Complying with all X-ray safety requirements.

2. Registering X-ray machines.

3. Preparing SOPs.

4. Appointing X-ray device custodians.

5. Ensuring proper training of operators.

iii. X-Ray Device Custodians.

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

1. Completing X-Ray-Generating Device Registration forms and submitting them to the X-Ray Device Control Office to register new electron microscopes, intentional X-ray devices, and new X-ray tube assemblies or source housings.

2. Making arrangements for operator training.

3. Maintaining a list of qualified operators authorized for particular machines.

4. Documenting that operators have read the appropriate SOPs and machine safety features.

5. Posting an authorized operator list near the control panel of each X-ray device.

6. Checking enclosure door safety interlocks every six months to ensure proper functioning and recording results on an interlock test log posted on or near the control panel.

7. Contacting the X-Ray Device Control Office before performing any repair, maintenance, and/or nonroutine work that could

cause the exposure of any portion of the body to the primary beam.

8. Meeting all requirements of Safe Operating Procedures, Special Work Permits, and Lockout/Tagout for Control of Hazardous Energy Sources for Personnel Safety (Red Lock Procedure).

iv. X-Ray Device Operators.

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

7. Wearing a TLD badge.

8. Knowing the SOP for every machine operated.

9. Notifying his/her supervisor of any unsafe or hazardous work situations.

10. Before reaching into the primary beam, verifying that the beam shutter is closed or that machine power is off.

11. Meeting all applicable training requirements before operating RPD.

12. Maintaining exposures ALARA.

GLOSSARY

Terms used consistent with their regulatory meaning.

Accelerator: A device employing electrostatic or electromagnetic fields to impart kinetic energy to molecular, atomic, or subatomic particles and capable of creating a radiological area (DOE Order 5480.25).

Examples include linear accelerators, cyclotrons, synchrotrons, synchrocyclotrons, free-electron lasers (FELs), and ion LINACs. Single and tandem Van de Graaff generators, when used to accelerate charged particles *other than electrons*, are also considered accelerators. Specifically *excluded* from this definition (per DOE 0 5480.25) are the following:

- Unmodified commercially available units such as electron microscopes, ion implant devices, and X-ray generators that are acceptable for industrial applications.

- Accelerator facilities not capable of creating a radiological area.

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

Access port: *See* port.

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

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

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

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

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

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

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

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

Compliance label: A label affixed to an intentional X-ray device certifying that the device has been surveyed and that safe operating requirements have been met.

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

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

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

Dosimeter: A device that measures and indicates radiation dose.

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

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

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

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

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

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

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

Floor: In this context, the underside external surface of the cabinet.

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

Gauge: A device that produces ionizing radiation for the purpose of measuring particular properties of a system.

Half-value layer (HVL): The thickness of a specified substance that, when introduced into a beam of radiation, reduces the dose rate by one-half.

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

Installation: A radiation source, with its associated equipment, and the space in which it is located.

Installation enclosure: The portion of an X-ray installation that clearly defines the transition from a noncontrolled to a controlled area and provides such shielding as may be required to limit the dose rate in the noncontrolled area during normal operations.

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

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

Ion: An atom, or molecule bearing an electric charge, or an electron that is not associated with a nucleus.

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

Lead equivalent: The thickness of lead affording the same attenuation, under specific conditions, as the shielding material in use.

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

Medical X-ray system: An X-ray system for medical use, generally categorized as either diagnostic or therapeutic. Diagnostic X-ray procedures are used to obtain images of body parts; therapeutic x-ray procedures are used to manage malignancies.

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

Occupancy factor: The factor by which the workload should be multiplied to correct for the degree or type of occupancy of the area specified.

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

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

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

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

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

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

Radiation source: A device or a material that is capable of emitting ionizing radiation.

Radiological control technician (RCT): Any person who is actively engaged in or who has completed facility-specific RCT training and qualification programs.

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

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

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

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

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

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

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

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

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

System barrier: The portion of an X-ray installation that clearly defines the transition from a Controlled Area to a Radiation Area and provides such shielding as may be required to limit the dose rate in the Controlled Area during normal operation.

Tenth-value layer (TVL): The thickness of a specified substance that, when introduced into a beam of radiation, reduces the dose rate to one-tenth of the original value. One TVL is equivalent to 3.3 HVLs.

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

Use factor: The fraction of the workload during which the useful beam is pointed in the direction under consideration.

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

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

Workload: A measure, in suitable units, of the amount of use of radiation equipment. For the purpose of this standard, the workload is expressed in milliampere-minutes per week for X-ray sources and in roentgens per week at 1 meter from the source for gamma-ray sources and high-energy equipment (such as linear accelerators, betatrons, etc.).

X-ray accessory apparatus: Any portion of an X-ray installation that is external to the radiation source housing and into which an X-ray beam is directed for making X-ray measurements or for other uses.

X-Ray Device Control Office: A team that establishes X-ray device program requirements and standards, provides X-ray device radiation protection consultation, and serves as the central point of contact for the management/control of X-ray devices. This function may have a facility-specific name.

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

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

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

X-ray installation: One or more x-ray systems, the surrounding room or controlled area, and the installation enclosure.

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

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

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

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

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