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DOE HANDBOOK

RADIOLOGICAL SAFETY TRAINING FOR ACCELERATOR FACILITIES

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

AREA TRNG

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Department of Energy
Technical Standards Program
Web Site at
http://www.hss.energy.gov/nuclearsafety/techstds/

Change Notice No.2 Radiological Training for Accelerator Facilities

Page/Section	Change
Throughout the document: Program Management Guide Instructor's Guide Student's Guide "Shall" and "Must" statements	Revised to: Program Management Instructor's Material Student's Material Reworded to non-mandatory language unless associated with a requirement document. References to overhead transparencies have been removed. The word "visitors" was removed from the table in Part1.
Part 1/Page 5/Para 2	Change: DOE-STD-1098-99 To: DOE-STD-1098-2008 And added reference to chapter 7 of Implementation Guide G 441.1-1C , *Radiation Protection Programs for Use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection*
Part 1/Page 11/Para 4	Change: DOE-HDBK-1122-99 To: DOE-HDBK-1122-2008
Part 1/Page 11/Para 5	Change: DOE-STD-1070-94 To: DOE-STD-1070-94, reaffirmed 1999 Added: The training program materials and processes are evaluated by HS-11 at least every five years as part of the DOE Technical Standards Program.
Part 1/Page 12/Para 2	Change: DOE-HDBK-1019-93 To: DOE-HDBK-1019-93, reaffirmed 1999
Part 1/Page 13/Bibliography	Change: U.S. Department of Energy, *DOE Fundamentals Handbook, Nuclear Physics and Reactor Theory*, DOE-HDBK-1019-93, Washington, D.C. (1993) To: U.S. Department of Energy, *DOE Fundamentals Handbook, Nuclear Physics and Reactor Theory*, DOE-HDBK-1019-93, reaffirmed 1999, Washington, D.C. (1993)
Part 1/Page 13/Bibliography	Change: U.S. Department of Energy, *Guide for Evaluation of Nuclear Facility Training Programs*, DOE-STD-1070-94, Washington, D.C. (1994) To: U.S. Department of Energy, *Guide for Evaluation of Nuclear Facility Training Programs*, DOE-STD-1070-94, reaffirmed 1999, Washington, D.C. (1994)
Part 1/Page 13/Bibliography	Change: U.S. Department of Energy, *Personnel Selection, Qualification, Training and Staffing Requirements at DOE Reactors and Non-Reactor Nuclear Facilities*, DOE Order 5480.20A, Washington, D.C. (1994) To: U.S. Department of Energy, Order 426.2, *Personnel Selection, Training, Qualification, and Certification Requirements for DOE Nuclear Facilities,*

	Washington, D.C.(2010)
Part 1/Page 13/Bibliography	Change: U.S. Department of Energy, *Guide to Good Practices for Training and Qualification of Instructors*, DOE-HDBK-1001-96, Washington, D.C. (1996) To: U.S. Department of Energy, *Guide to Good Practices for Training and Qualification of Instructors*, DOE-HDBK-1001-96, reaffirmed 1999, Washington, D.C. (1996)
Part 1/Page 13/Bibliography	Change: U.S. Department of Energy, 10 CFR Part 835,*Occupational Radiation Protection*, Washington, D.C. (1998) To: U.S. Department of Energy, 10 CFR Part 835,*Occupational Radiation Protection*, Washington, D.C. (2007)
Part 1/Page 13/Bibliography	Change: U.S. Department of Energy, *Radiological Control*, DOE-STD-1098-99, Washington, D.C. (1999) To: U.S. Department of Energy, *Radiological Control*, DOE-STD-1098-2008, Washington, D.C. (2008)
Part 1/Page 13/Bibliography	Change: U.S. Department of Energy, *Safety of Accelerator Facilities*, DOE Order 420.2A, Washington, D.C. (2001) To: U.S. Department of Energy, *Safety of Accelerator Facilities*, DOE Order 420.2C, Washington, D.C. (2005)
Part 2/Page 5/Para 7	Change: DOE-HDBK-1019-93 To: DOE-HDBK-1019-93, reaffirmed 1999.
Part 2/Page 33/Para F	Change: DOE Order 5480.25 To: DOE Order 420.2C
Part 3/Page 5/Para 7	Change: DOE-HDBK-1091-93 To: DOE-HDBK-1019-93, reaffirmed 1999

Change Notice No.1 Radiological Training for Accelerator Facilities

Cover sheets parts 1 through 5	Change: Office of Environment, Safety & Health To: Office of Health, Safety and Security
Part 1, page 5, 2nd last para	Change: The DOE Office of Worker Protection Policy and Programs (EH-52) is responsible for .... To: The DOE Office of Health, Safety and Security's Office of Worker Safety and Health Policy (HS-11) is responsible for ...
Part 1, page 5, 2nd Bottom	Insert: Copies of this Handbook may be obtained from the DOE Radiation Safety Training Home Page Internet site (http://www.hss.energy.gov/radiation/RST/rstmater.htm).
Part 1, page 11, Evaluating Training Program Effectiveness 1st para	Change: "Verification of the effectiveness of Radiological Control Training for Supervisors should be accomplished by..." To: "Verification of the effectiveness of Radiological Safety Training for Accelerator Facilities should be accomplished by..." Change "DOE/EH" to "DOE/HSS"

(PART 1 OF 4)

Radiological Training for Accelerator Facilities

Program Management

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

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Table of Contents

Introduction 5
- Purpose and Scope 5
- Management Content 5
- Training Program Goal 5
- Organizational Relationships and Reporting Structure 5

Instructional Materials Development 6
- Target Audience 6
- Prerequisites 6
- Training Material 6
- Exemptions 7

Training Program Standards and Policies 7
- Qualification of Instructors 7
- Technical Qualifications 7
- Instructional Capability and Qualifications 8
- Selection of Instructors 9
- Test Administration 10
- Program Records and Administration 10
- Training Program Development/Change Requests 11
- Audits (internal and external) 11
- Evaluating Training Program Effectiveness 11

Course-Specific Information 11
- Purpose 11
- Course Goal 11
- Target Audience 11
- Course Description 12
- Prerequisites 12
- Length 12
- Test Bank 12
- Retraining 12
- Instructor Qualifications 12
- Materials Checklist 13
- Bibliography 13

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Introduction

Purpose and Scope

This beginning section discusses in general recommendations for the implementation of radiation safety training. Course specific guidance begins on page 10.

This non-mandatory Handbook describes a recommended implementation process for conducting the radiation safety training required by Title 10 Code of Federal Regulations Occupational Radiation Protection, (10 CFR 835) Subpart J and as recommended in chapter 7 of Implementation Guide G 441.1-1C , *Radiation Protection Programs for Use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection*, and as outlined in the DOE standard DOE-STD-1098-2008, *Radiological Control* (RCS). The Handbook is to assist those individuals, both within the Department of Energy (DOE) and Managing and Operating (M&O) contractors, identified as having responsibility for implementing the training required by 10 CFR 835 and recommended by the RCS.

Program Management Content

The Program Management is divided into the following sections:

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

Training Program Goal

The goal of the training program is to provide a baseline knowledge for those individuals completing the training. Use of the DOE developed material provides personnel with the information necessary to perform their assigned duties at a predetermined level of expertise. Implementing the training program helps ensure consistent and appropriate training of personnel.

Organizational Relationships and Reporting Structure

The DOE Office of Health, Safety and Security's Office of Worker Safety and Health Policy (HS-11) is responsible for approving and maintaining the DOE developed training materials associated with the training program.

The establishment of a comprehensive and effective contractor site radiological control 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.

Copies of this Handbook may be obtained from the DOE Technical Standards Page:
https://www.standards.doe.gov/

Instructional Materials Development

Target Audience

Course instructional materials were developed for specific employees who are responsible for knowing or using the knowledge or skills for each course. 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 the program consist of lesson plans, study material and handouts. The training content should be presented in its entirety.

Supplemental material and training aids may be developed to address site-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 site-specific information and training aids.

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

Training Program Standards and Policies

Qualification of Instructors

The technical instructor plays a key role in the safe and efficient operation of DOE facilities. Workers should be well qualified and have a thorough understanding of the facility's operation, such as processing, handling, and storage of materials, and maintenance of equipment. Workers should know how to correctly perform their duties and why they are doing them. They should know how their actions influence other worker's responsibilities. Because workers' actions are so critical to their own safety and the safety of others, their trainers should be of the highest caliber. The technical instructor should understand thoroughly all aspects of the subjects being taught and the relationship of the subject content to the total facility. Additionally, the instructor should 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 techniques to ensure that workers receive the highest quality training possible. This is possible only 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 should 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 TECHNICAL QUALIFICATIONS
Accelerator Facilities Personnel, DOE Employees	Accelerator Hazards and Safety Training	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, AND Completion of all qualification requirements for the senior-level radiation protection technician position at the trainees' facility or a similar facility.

Methods for verifying the appropriate level of technical competence may include the 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 qualification, certification by the American Board of Health Physics and/or registration by the National Registry of Radiation Protection Technologists, 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, 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 them 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 activities.
- Use appropriate instructional materials and visual aids to meet the lesson objectives.
- Administer performance and written tests.
- Ensure that 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 document. 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, and
- maintain records of previous training, education, and work experience

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

Test Administration

A test bank of questions for this training, with site specific information, should be developed and the content validated. As the test banks are used, statistical validation of the test bank should be performed in order 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 should generally be used to demonstrate satisfactory completion of theoretical classroom instruction. The following are some minimal recommendations 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 are not released either before or after the test is administered.
- Trainees receive feedback on their test performance.
- Test banks undergo statistical analysis.
- For the first administrations of tests, a minimum passing score of 80% should be required for a passing score. As statistical analysis of test results is 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 completion of tests.
- 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 provided or alluded to.
- 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 sent to the DOE Technical Standards Program using the form "Document Improvement Proposal" provided at the conclusion of the material, as provided on the DOE Technical Standards website.

Audits (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 training program materials and processes are evaluated by HS-11 at least every five years as part of the DOE Technical Standards Program. The evaluation may include a comparison of program elements with applicable industry standards and requirements.

Evaluating Training Program Effectiveness

Verification of the effectiveness of Radiological Safety Training for Accelerator Facilities should be accomplished by surveying a limited subset of former students in the workplace. This evaluation should include observation of practical applications and discussion of the course material. DOE/HSS has issued guidelines for evaluating the effectiveness of radiological training through the DOE Operations Offices and DOE Field Offices. These guidelines are available as an attachment to the Program Management Guide of DOE-HDBK-1122-2008, *Radiological Control Technician Training.*

For additional guidance, refer to DOE-STD-1070-94, reaffirmed 1999, *A Guide for Evaluation of Nuclear Facility Training Programs.* The guidelines contained in these documents are relevant for the establishment and implementation of post-training evaluation programs.

<u>Course-Specific Information</u>

Purpose

This section is to assist those individuals assigned responsibility for implementing the *Radiological Training for Accelerator Facilities*. Standardized implementation of this training helps ensure consistent and appropriate training for all personnel.

Course Goal

Upon completion of this training, the student will have a basic understanding of the radiological characteristics of accelerators and understand the precautions and safeguards needed for working in an accelerator facility.

Target Audience

Individuals who have assigned duties in accelerator facilities.

Course Description

This course illustrates and reinforces the skills and knowledge needed to provide personnel with an understanding of the radiological characteristics of accelerators and the precautions needed for working with or around them in a DOE facility. This course is designed to meet Article 664 of the RCS for individuals who have assigned duties in an accelerator facility.

Prerequisites

Training which is considered commensurate with site-specific hazards. Radiological Worker I or II or the equivalent is recommended prior to receiving this accelerator facilities safety training. Completion of Module 1 of Volume 1 of DOE-HDBK-1019-93, reaffirmed 1999, *DOE Fundamentals Handbook, Nuclear Physics and Reactor Theory*, is also recommended.

Length

2 - 4 hours (depending on site-specific information)

Test Bank

Test banks, as applicable, should be developed by the sites, incorporating site-specific information.

Retraining

Retraining is not required for this course.

Instructor Qualifications

Instructors of this course have a major role in making it successful and meeting the specified objectives. Instructors should have related experience and be technically competent. In this course it is imperative that the instructor have the background and experience of working in an accelerator facility. Instructors should be able to relate their own work experience to the workers in an accelerator facility. Instructors should 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 recommended.

Certification:

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

Experience:

At least five years of applied radiological protection experience in an operating radiological facility is preferred. Experience in radiological protection at the applicable accelerator facility, such as completion of all qualification requirements for the senior-level radiation protection technician position at the trainees' facility or a similar facility is suggested. The areas of experience should include:

- Radiological controls associated with accelerators.
- Conducting surveys and monitoring at accelerator facilities.

Intimate knowledge of Federal regulations and guidance, and best industry practices, pertaining to radiological protection. 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. .

- Program Management
- Instructor's Material
- Student's Material

The following checklist should be used before training is provided to ensure that equipment is available and working.

- Screen
- Flip chart
- Markers

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U.S. Department of Energy, McCall, R.C. et. al, *Health Physics Manual of Good Practices for Accelerator Facilities*, SLAC-327, Stanford Linear Accelerator Center, Stanford, CA, April 1988

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(Part 2 of 4)

Radiological Training for Accelerator Facilities

Instructor's Material

Office of Health, Safety and Security

U.S. Department of Energy

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Table of Contents

Page

COURSE MATERIAL 19
Course Goal 19
Target Audience 19
Description 19
Prerequisites 19
Length
Terminal Objectives 20
Enabling Objectives 20
Training Aids 20
Equipment Needs 21
Student Material 21

LESSON SUMMARY 22
Introduction 22
Terminal Objective 22

COURSE CONTENT 23
General

I. HISTORY AND USES OF ACCELERATORS 24
A Definition 24
B Need for Accelerators 24
C The Development of the Accelerator 24
D Van de Graaff Generator 25
E Cockcroft-Walton Accelerator 25
F Linear Accelerators 25
G Lawrence and the Development of the Cyclotron 25
H Synchrotrons 26
I Colliders 26
J Purpose and Uses 27

II. FACILITY DESCRIPTION 27
A Types of Accelerators in Use at Facility (Facility-Specific) 27
B Types of Particles Accelerated at the Facility (Facility-Specific) 27
C Facility Layout and Description of Areas/Components (Facility-Specific) 28

III. RADIOLOGICAL CONCERNS 28
A Prompt Radiation 28
B Residual Radioactivation 31
C Ancillary Sources 34

IV. TYPES OF CONTROLS 35
A Engineered Controls 36
B Administrative Controls 37
C Accelerator Facility Access Modes (Facility-Specific) 38
D Configuration Control Program 39

V. MONITORING 40
A Qualification of Monitors 40
B Area Monitoring 40
C Prompt Radiation Monitoring 41
D Residual Radiation 41
D Environmental Monitoring 43
E Personnel Monitoring 43

VI. RADIOACTIVE WASTE ISSUES 44
A Sources of Radioactive Waste 44
B Minimizing Radioactive Waste 46
C Mixed Waste 46
D Minimizing Mixed Waste 46

VII. ABNORMAL CONDITIONS 47
A Loss of Beam Containment (Facility-Specific) 47
B Radiation Overexposure (Facility-Specific) 47
C Fires (Facility-Specific) 47
D Loss of Radioactive Material (Facility-Specific) 48
E Facility Alarms (Facility-Specific) 48
F Safety Assessment Document (SAD) 48

VIII. LESSONS LEARNED 48

IX. REVIEW OF COURSE OBJECTIVES 49

DEPARTMENT OF ENERGY - COURSE PLAN

Course Goal:	Upon completion of this training, the student will have a basic understanding of the characteristics of accelerators and the precautions and safeguards needed for radiological safety while working in an accelerator facility.
Target Audience:	Individuals who have been assigned radiological duties (e.g., duties typically requiring radiological worker training or equivalent) in accelerator facilities.
Description:	This course illustrates and reinforces the skills and knowledge needed to provide personnel with an understanding of the characteristics of accelerators and the radiological safety precautions needed for working at an accelerator facility. Note: This lesson is not intended to be a requirement of all accelerator facilities but rather a resource to be used at the discretion of the facility training organization. Accelerator facilities may use any portion of this material. Note: Facility-specific information that requires each facility to input information is denoted as "Facility-Specific."
Prerequisites:	Training that is considered commensurate with facility-specific hazards.

Training which is considered commensurate with site-specific hazards. Radiological Worker I or II or the equivalent is recommended prior to receiving this accelerator facilities safety training. Completion of Module 1 of Volume 1 of DOE-HDBK-1019-93, reaffirmed 1999, *DOE Fundamentals Handbook, Nuclear Physics and Reactor Theory*, is also recommended.

Length: 2-4 hours (depending on facility-specific information).

Terminal Objectives: At the end of this course, the participant should be able to demonstrate a basic understanding of the characteristics of accelerators and the radiological precautions for working at an accelerator facility.

Enabling Objectives:

EO-01 IDENTIFY uses for accelerators.
EO-02 STATE the type(s) of accelerators at the facility.
EO-03 STATE type(s) of particles accelerated.
EO-04 DEFINE prompt radiation.
EO-05 DISCUSS the biological effects of radiation characteristic of accelerators.
EO-06 IDENTIFY prompt radiation sources at the facility.
EO-07 DEFINE radioactivation.
EO-08 IDENTIFY activation sources at the facility.
EO-09 IDENTIFY ancillary sources at the facility.
EO-10 IDENTIFY activation products.
EO-11 IDENTIFY engineered and administrative controls at accelerator facilities and personal protective equipment.
EO-12 DESCRIBE each access mode at the facility and access to beam and beam containment including interlocks and warning devices and systems.
EO-13 DISCUSS site configuration control program.
EO-14 DISCUSS special radiological surveys and techniques.
EO-15 STATE purpose of initial entry survey.
EO-16 DISCUSS special instruments and measurement techniques.
EO-17 STATE site requirements for removing material from beam enclosure.
EO-18 IDENTIFY methods to minimize radioactive waste at the facility. (Facility-Specific)
EO-19 IDENTIFY facility alarms and responses to abnormal conditions. (Facility-Specific)

Training Aids: Facility-Specific.

Equipment Needs:

- o Screen.
- o Flip chart.
- o Markers.

LESSON SUMMARY

Introduction

Welcome students to the course.

Introduce self and instructor team.

Define logistics.

- safety briefing - exits
- restrooms
- hours
- breaks
- sign-in sheets
- test - accountability
- end of course evaluation

Remind the participants that they need to have completed Radiological Worker Training prior to this course. They should be familiar with terms like rem, contamination, etc.

Terminal Objective

At the end of this course, the participant should be able to demonstrate a basic understanding of the characteristics of accelerators and precautions for working at an accelerator facility.

State Course Objectives.

Course Content

Briefly review the content of the course, noting that there is a logical sequence ("flow") and that the material covered will be related to the circumstances they can expect to find in the facility workplace and procedures. (You will be inserting and facility-specific accelerator information.)

1. History and Uses of Accelerators.

2. Facility Description.

3 Radiological Concerns.

4. Types of Radiological Controls for Accelerator Facilities.

5. Monitoring at Accelerator Facilities.

6. Radioactive Waste Issues.

7. Abnormal Conditions at Accelerator Facilities.

8. Lessons Learned.

9. Summary and Review.

General

Implementation
This training should be used to supplement the DOE developed radiation safety training materials for personnel working at or having access to DOE accelerator facilities. This training is multi-faceted, and different sections can be applied to various target groups.

I. HISTORY AND USES OF ACCELERATORS

A. Definition

Accelerators are devices employing electrostatic or electromagnetic fields to input kinetic energy to molecules, atomic or subatomic particles. This training is provided because accelerators also are capable of creating a radiological area and other radiological hazards.

B. Need for Accelerators

In the early 1900s, radioactive particles could be obtained only from materials found in nature. The studies that physicists wanted to perform required both higher intensities and higher energies than were obtainable from the natural sources. The ability to vary energy and intensity to suit a particular experiment was also desirable.

In the 1930s, scientists began to build machines that produced the needed degree of control. These machines were called accelerators.

C. The Development of the Accelerator

The earliest accelerators were simple vacuum tubes in which electrons were given an increase in energy by the voltage difference between two oppositely charged electrodes.

1. Acceleration
   The acceleration of the electron by this electrical force also increases the energy of the electron.

2. Electron volt
   The amount of acceleration is determined by the potential difference measured in volts (V) in this electrical field.

   One electron volt (eV) is the energy gained by an electron accelerated through a potential difference of one volt.

   An electron accelerated across a gap by means of a 10,000 volt, or 10 kilovolt (kV), potential difference is said to have gained 10,000 electron volts (10 keV) of energy after crossing the gap.

D. Van de Graaff Generator

One of the first machines to produce laboratory- accelerated particles was the Van de Graaff generator.

1. Operation
The Van de Graaff consists of a polished metal sphere and a moveable belt. The function of the belt is to carry an electrical charge up to the sphere where it is stored. This process can be continued until a very high potential is developed in the sphere.

2. Early generators
In 1929, Van de Graaff built a pilot machine capable of generating 80,000 volts. In 1931, a 1.5 million-volt (MeV) machine was built at Princeton.

3. State of the Art
A 25 MeV machine was built and operated at Daresbury Laboratory in the United Kingdom.

E. Cockcroft-Walton Accelerator

In 1932 in England, John D. Cockcroft and Ernest T.S. Walton constructed what is called a linear accelerator using a high-voltage source to accelerate protons through 700,000 volts (700 keV).

Straight-line accelerators suffer from the disadvantage that the finite length of flight path limits the particle energies that can be achieved.

F. Linear Accelerators

From the first simple machines (Cockcroft-Walton and Van de Graaff machines) evolved the larger and more elaborate machines. The modern example of this type of accelerator is the linear accelerator, a sophisticated machine used in many scientific and medical applications.

G. Lawrence and the Development of the Cyclotron

The great breakthrough in accelerator technology came in 1930 with Ernest O. Lawrence's invention of the cyclotron.

1. Operation

In the cyclotron, magnets guide the particle along a spiral path, allowing a single electric field to apply many cycles of acceleration.

2. Prototype

Soon unprecedented energies were achieved, and the steady improvement of Lawrence's simple machine has led to today's synchrotrons, whose endless circular flight paths allow particles to gain huge energies by passing millions of times through the electric fields that accelerate them.

H. Synchrotrons

A synchrotron accelerates particles using electric fields over and over in a circular path. Magnetic fields are used to bend the particles' trajectories and keep them moving in a circle. The accelerated particles lose energy rounding the curves, so energy must be continuously supplied. The beam is extracted heading toward targets and detectors.

I. Colliders

Until 30 years ago, all accelerators were so-called fixed-target machines in which the speeding particle beam was made to hit a stationary target of some chosen substance.

In the early 1960s, physicists had gained enough experience in accelerator technology to be able to build colliders in which two carefully controlled beams are made to collide with each other at a chosen point. The beams for colliders may come from two synchrotrons or two linear accelerators.

Lesson Plan | Notes

J. Purpose and Uses

EO-01 IDENTIFY uses for accelerators.

Accelerators were originally designed to study (research) the structure of matter. Accelerators today are used not only for basic research purposes, but for many other applications such as:

- Production of radioisotopes, such as tritium.
- Generation of bremsstrahlung for radiography and radiation therapy.
- Induction of fusion.
- Pumping for lasers.
- Detoxification of hazardous waste.
- Actinide transmutation.
- Production of synchrotron radiation.
- Sterilization of food and surgical equipment.
- Medical radiation therapy.

Define the terms, such as bremsstrahlung and actinide transmutation as necessary.

II. FACILITY DESCRIPTION

EO-02 STATE the type(s) of accelerators at the site.

A. Types of Accelerators in Use at Facility (Facility-Specific)

Each facility should discuss the types of accelerators in use at the site.

Electrostatic accelerators
- Cockcroft-Walton.
- Van de Graaff, Tandem Van de Graaff.

Linear accelerators (Linac)
- Resonant cavity (standing wave).
- Traveling wave.

Cyclic accelerators
- Synchrotron.
- Cyclotron.
- Betatron.

B. Types of Particles Accelerated at the Facility (Facility-Specific)

C. Facility Layout and Description of Areas/Components (Facility-Specific)

- Injectors.
- Target areas.
- Experimental areas.
- Beamlines.
- Control room.
- Shielding structures.

Each facility should describe and give locations of major components and areas. Discuss radiological hazards associated with the areas/ components.

III. RADIOLOGICAL CONCERNS

EO-04 DEFINE prompt radiation.

EO-05 DISCUSS biological effects of radiation characteristic of accelerators.

EO-06 IDENTIFY prompt radiation sources at the facility.

A. Prompt Radiation

Prompt radiation includes the accelerated particle beam and the radiation produced when the beam interacts with matter or changes direction. It is only present when a beam is operating or being accelerated.

1. Primary beam

The primary beam consists of accelerated charged particles prior to any interactions.

The primary beam is the most intense form of radiation present at an accelerator facility and is made inaccessible to personnel through engineering design and administrative controls.

Direct exposure to a particle beam can result in a potentially dangerous, or even lethal, dose of radiation.

EO-03 STATE type(s) of particles accelerated.

Lesson Plan | Notes

2. Secondary beam

Secondary beam is produced by interaction of the primary beam with targets or beamline components. The secondary beam may consist of:

- Electromagnetic radiation.
- Neutrons.
- Charged particles.
- Other elementary particles.

EO-14 DISCUSS special radiological surveys and techniques. As applicable, discuss fundamental particles, the hadron cascade or the radiation field inside the beam caves.

3. Skyshine

Skyshine is the radiation scattered from air molecules. Accelerator-produced skyshine is usually neutron radiation, scattered after emerging more or less vertically from the shielded enclosure. It can cause elevated radiation fields at ground level considerable distances from the source.

Define the terms.

Due to typical facility design, photon skyshine is usually less of a problem but is a consideration, particularly where radioactive materials are stored.

4. Electromagnetic radiation

a. Bremsstrahlung: (photons emitted through the deceleration of charged particles passing through matter).

b. Electromagnetic cascades: (multiple photons emitted through high-energy interactions).

c. Synchrotron radiation: (photons emitted as the charged particles are accelerated in a curved path).

5. Neutrons

Neutrons can be produced through nuclear interactions of the primary or secondary beam with matter. They can also be produced by interaction of high-energy photons about with matter (photoneutron reaction). The photoneutron reaction typically requires photons with energy in excess of 10 MeV.

Each facility should describe potential sources of neutron radiation exposure, including types of applicable bombardment reactions.

a. Neutron radiation is a concern within any area where the beam can interact with physical objects.

b. Location of potential sources of neutron radiation exposure. (Facility-Specific).

6. Muons

Muons are particles that are physically similar to electrons, but about 200 times heavier. Like electrons, they can be positively or negatively charged

GeV = $1x10^9$ eV

a. Muons are produced by several mechanisms and require photon energies greater than 212 MeV or proton energies greater than 140 MeV.

b. Muons are not usually seen in significant amounts at machines with energies less than 1 giga electron-volt (GeV).

c. Muons travel mainly in the direction of the beam that produced them with very little deviation from the beam path. They are a concern directly downstream of targets, beam dumps, etc. Muons are ionizing particles and can deliver a very high dose.

d. Muons lose energy only through ionization and are very penetrating. Large amounts of earth or steel are typically used to shield muons.

EO-16 DISCUSS special instruments and measurement techniques.

Lesson Plan | Notes

7. Facility-Specific

Identify facility-specific prompt radiation sources.

EO-06 IDENTIFY prompt radiation sources at site.

B. Residual Radioactivation

EO-07 DEFINE radioactivation.

The process by which materials become radioactive is commonly referred to as "radioactivation" or simply "activation." Generally, energies above 10 MeV are needed to activate materials for particles other than neutrons.

EO-10 IDENTIFY activation products.

1. Residual radioactivity

   Activated materials emit radiation from radioactive decay after shut-off of the beam.

2. Contaminated material versus activated material.

   Contaminated materials are items with fixed or removable surface contamination.

   Give examples of destructive means.

   Activated material is radioactive material dispersed throughout the item and is not removable except through some type of destructive means as discussed below.

   a. Activated materials normally do not present a potential loose contamination hazard except during activities such as:

      - Grinding.
      - Burning.
      - Machining.
      - Handling coolant water filters.

      Target spallation may also create contamination without any of the above (or similar) physically destructive operation applied.

Lesson Plan | Notes

b. Activated materials are normally controlled based on the external radiation dose rate.

3. Activated materials

EO-08 IDENTIFY activation sources at the facility.

All materials located within an accelerator enclosure have the potential to be radioactivated if subjected to primary or secondary beams. Most of these activation radionuclides have a short half-life (the time it takes for one-half of the atoms to decay).

Materials that may become radioactive include:

- Any material within the accelerator enclosure.
- Beamline components.
- Air.
- Cooling liquids and working fluids.

Discuss how the capture cross-section differs with different material and how this affects activation. Discuss the term: barn.

4. Beamline components

Beamline components may become radioactive depending on:

- Nature of the material.
- Proximity to the beam.
- Beam characteristics.

See Glossary for definitions.

Items that intercept a portion of the beam are most likely to be activated and contaminated. Among those items that have the highest probability for activation are:

- <u>Targets</u>: devices to intercept a portion of the beam for purposes of producing secondary beams.
- <u>Beam dumps or stops</u>: used to absorb the beam.
- <u>Collimators and scrapers</u>: used to remove unwanted diffuse "halo" that often exists surrounding the central beam.
- <u>Septa and other magnets</u>: used to align and direct beams.
- <u>Cavities and beamline</u>: the beamline piping and items such as resonating cavities, detectors, etc.

Lesson Plan | Notes

5. Air

Air, dust, and other gases in the accelerator enclosure may be activated. Typically, the activation products are short-lived gaseous radionuclides of the elements in the air or particulate, in the case of dust particles. An example is Oxygen-15 from Nitrogen-14.

(Facility Specific) Each Facility should cover their nuclides of concern, such as:
O-15
N-13
C-11
Cover facility's procedures for entering enclosure after beam shut-off.

6. Liquids

(Facility-Specific) Include likely facility locations.

a. <u>Cooling water</u>: used for cooling beamline components (activation products such as tritium (H-3), beryllium (Be-7) and possible pipe wear products or erosion of the pipe surfaces).

See Section VI, for methods to dispose of activated liquids.

b. <u>Oil in vacuum pumps (beam line components)</u>.

c. <u>Cryogenic fluids</u>: liquid helium and nitrogen are used frequently to cool components.

7. Facility-Specific

EO-08 IDENTIFY activation sources at site.

Facility should cover items that routinely become activated due to accelerator operation.

8. Contamination

Materials and activities that could create contamination concerns.

Cover each source as applicable to the facility.

a. <u>Surface coating</u>: such as paint, oxidation, and rust may present a contamination problem. Such coatings may be easily removable and may be present in areas not commonly accessed, such as beam dump vaults.

b. Compounds: such as grease, sealants, gaskets, and anti-seize coatings may be activated depending on their composition. Prior to maintenance, these compounds should be chosen carefully to minimize the production of contamination if possible. These materials may not be accessible until after components are disassembled; therefore, the need for carefully planned maintenance activities involving such compounds should be highlighted.

Show picture of filter/resin media or bed as applicable.

c. Impurities: Impurities in cooling water systems can be a source of contamination. This source may be found in a filter/resin media system.

d. Activities: (Facility-Specific) routine work areas where contamination control should be considered:

- Machining of radioactive materials.
- Cooling water filters.
- Accessing beamline.
- Maintenance.
- Target removal.
- Etc.

EO-09 IDENTIFY ancillary sources at site.

C. Ancillary Sources

Accelerators employ devices to impart energy to particles or redirect them during the acceleration process. These devices may emit ionizing radiation while they are operating.

Lesson Plan | Notes

1. Klystrons

Klystrons provide power to accelerate charged particles. They emit X-rays during operation.

2. Radiofrequency cavities

These devices accelerate charged particles using electromagnetic fields. Electrical discharges within the RF cavity cause photon (ionizing radiation) emission.

3. Electrostatic separators/Septa

These devices split a particle beam into two beams using static electric fields. The high voltages associated with these devices cause electrons to accelerate in the vacuum within the beamline. They emit X-rays. Septa are also a high source of activation and residual radiation.

Septa are also a high source of activation and residual radiation.

4. Facility-Specific

Location of facility-specific ancillary sources.

IV. TYPES OF CONTROLS

EO-11 IDENTIFY engineered and administrative controls at accelerator facilities.

EO-12 DESCRIBE each access mode at the facility and access the beam and beam containment including interlocks and warning devices and systems.

Controls are used at accelerator facilities to protect personnel from exposure to ionizing radiation and other hazards including:

- Electrical.
- Mechanical.
- Cryogenic.
- Non-ionizing radiation.

The design of an effective safety program incorporates a combination of:

- Engineered controls.
- Administrative controls.
- Personal protective equipment, e.g., respirators, protective clothing, etc.

However, per 10 CFR 835.1001(c), the primary methods used shall be physical design features. Administrative controls and procedural requirements should be employed only as supplemental methods to control radiation exposure.

A. Engineered Controls

Engineered controls include equipment and structures (passive or active) designed to protect personnel from hazards.

1. Passive engineered controls

Once installed, passive engineered controls require no further action to perform their intended function. Passive engineered controls may include:

a. Radiation shielding: such as concrete blocks, iron plates, lead bricks and earth berms.

b. Barriers: such as fences, locked gates, and doors.

c. Facility-Specific: facility-specific passive engineered controls.

2. Active engineered controls

Active engineered controls include devices that sense changing conditions and can trigger a safety action.

Show picture of facility safety interlock devices.

a. Safety interlock devices.

- Area radiation monitors.
- Access sensors, magnetic and mechanical.
- "Crash" or "scram" buttons.

Show active controls.

b. Facility-specific: Facility-specific active engineered control devices.

B. Administrative Controls.

EO-11 IDENTIFY engineered and administrative controls at accelerator facilities.

Programs and activities which personnel should implement to provide protection from hazards.

1. Search and secure (sweep) procedures.

   These are procedures used to verify that no personnel remain in a beamline enclosure when it is being prepared to receive beam.

Explain facility-specific search procedures.

2. (Facility-Specific) search procedures.

3. Controlled access procedures (including key controls).

   Procedures that allow personnel to access a beamline enclosure while it remains interlocked. There is no physical search of the area before the beam is restored.

4. (Facility -Specific) controlled access procedures.

Discuss limiting conditions and hold points.

5. Radiological work permits (RWPs).

   RWPs provide written documentation of job descriptions, radiological conditions, and the required protective controls.

6. Configuration control procedures.

   Procedures to ensure that important information about the configuration of a facility is accurate and that the configuration retains its functional purpose.

7. Radiological monitoring programs.

   Provide assurance that the accelerator facility operates within the radiological safety design specifications and ALARA goals.

8. Warning indicators.

   - Status lights.
   - Alarms.

Discussed in Section V, Monitoring. Show picture/apparatus of facility warning indicators.

(Facility-Specific) Use facility-specific terminology.

C. Accelerator Facility Access Modes (Facility-Specific)

The status or mode of accelerator enclosures regarding accessibility are covered below. Access modes change with the beam status.

1. Normal or open access mode

   Beam area is not interlocked and beam cannot operate. Access to these areas is unrestricted after a radiation survey to identify and isolate areas of activation or contamination.

2. Search & secure mode

   Operators physically search enclosures prior to beam operation to ensure that no personnel remain in the enclosure when it is secured for operation.

3. Controlled access mode

   a. Beam area: Beam area has been searched and secured and remains interlocked, however, beam cannot operate.

      Limited personnel access is allowed. There is no search of area following the access.

   b. Procedure: Controlled access procedure (Facility-Specific).

EO-12 DESCRIBE each access mode at site.
Explain that this classroom training does not by itself qualify trainees to make controlled access. Additional facility-specific training (hands-on practice factors?) is required. Describe how trainees may obtain this training. Discuss accountability for those who accessed. Convey this by facility-specific demonstration or video.

Discussed in IV. D. Configuration Control program, give examples.

Lesson Plan | Notes

4. Test mode

Certain devices, (e.g., magnets) may be energized to allow testing. Limited personnel may access but should be aware of hazardous conditions (e.g. electrical power).

5. Exclusion mode

EO-13 DISCUSS site configuration control program.

Beam may be present. No access is allowed.

D. Configuration Control Program

The facility design should continue to meet its intended function while providing for adequate personnel safety. Configuration control ensures that only authorized changes are made and that any changes made continue to provide adequate personnel safety.

1. Elements of a program

Configuration control programs for accelerator facilities include:

- Inventory and labeling of controlled devices.
- Periodic inspections.
- Procedures for change and/or restoration of configuration.
- Testing to verify proper configuration.

Show picture of a device that is labeled as a configuration controlled item.

2. Structures and equipment.

These should be maintained in a specific configuration to perform the desired safety function.

Examples include:

- Radiation shielding.
- Magnets.
- Stops.
- Detectors.
- Interlocks and access system wiring.

EO-11 DISCUSS site configuration control program.

3. (Facility-Specific) configuration control procedures.

V. MONITORING

Monitoring refers to the checking, testing, and surveying of individuals, work areas, materials and equipment for ionizing radiation and radioactivity.

Monitoring for radiation at accelerators can be complicated. Special techniques and instrumentation may be necessary due to the existence of:

- Mixed radiation fields (photons, protons, neutrons, etc.).
- Pulsed beams.
- Very high energy radiation.
- High intensities of radiation (dose rates).
- Magnetic and RF fields.

(Facility-Specific) Discuss facility requirements for qualifications to perform surveys.

A. Qualification of Monitors

Monitoring is only performed by Radiological Control Personnel or others who are specifically trained and qualified to perform monitoring.

EO-15 STATE purpose of initial entry survey.

B. Area Monitoring

Monitoring of areas at accelerator facilities refers to monitoring for radiation and contamination using fixed and portable instruments. Monitoring may include measuring for:

- Prompt radiation.
- Residual radiation.

and includes:

- Work areas.
- Surfaces.
- Water.
- Air.
- Non-work areas outside of enclosures.

Lesson Plan | Notes

C. Prompt Radiation Monitoring

(Facility-Specific) Each facility should discuss facility-specific instruments, settings, locations, and consequences of tampering.

Prompt radiation monitoring is to ensure radiation levels outside of accelerator facilities are maintained below regulatory limits to workers and the general public, and as a means to detect deficiencies in beam containment.

1. Instrumentation

   Prompt radiation surveys may utilize fixed and portable instruments.

2. Pulsed radiation

   (Facility-Specific) Show example of instrument.

   Prompt pulsed radiations must be measured with specialized survey instruments. Ion chambers are typically used.

3. Neutron radiation.

   Neutron monitoring is complicated and should be performed by an individual qualified to perform neutron surveys.

D. Residual Radiation

Radioactive materials may be found at accelerator facilities in the form of:

Define removable and fixed contamination if not covered in previous training.

- Removable contamination.
- Fixed contamination.
- Activated materials.
- Volume contamination.

1. Residual radiation monitoring

   Residual radiation is typically monitored with portable instruments and contamination swipes. Types of monitoring may include:

   - Work areas.
   - Items/materials.
   - Operational systems.

Lesson Plan	Notes
2. Monitoring instruments Special instruments may be needed for monitoring residual activity in materials depending on: - Nature of material. - Physical form (i.e., liquids).	(Facility-Specific) Each facility should discuss the locations and instruments used for monitoring induced activity.
3. Work areas Types of work area surveys include: - Radiation dose rate surveys. - Loose surface contamination surveys. - Air sampling, including continuous air monitoring.	(Facility-Specific) Each facility should discuss their work area monitoring program.
4. Items/materials monitoring (Facility-Specific) The purpose of monitoring materials is to ensure radioactive materials are identified and controlled within controlled areas. All items/materials should be surveyed prior to removal from areas of potential activation/contamination. Typically this includes any material inside the beam enclosures, targets and shielded structures.	EO-17 STATE site requirements for removing material from beam enclosures.
5. Cooling water and other systems. Typical monitoring may include: - Sampling component cooling water. - Monitoring filter media.	(Facility-Specific) Each facility should discuss their environmental monitoring program.

Lesson Plan	Notes
E. Environmental Monitoring Environmental sampling/monitoring may include: - Prompt radiation levels (neutrons, skyshine, muons, etc.). - Radiation levels at site boundary from storage areas, etc. - Sampling of exhausted air from beam housings. - Surface/ground water (on and off site). - Monitoring of radiation levels at site boundary. - Soil/vegetation/deposition near liquid discharges and air exhaust.	(Facility-Specific) Each facility should discuss their monitoring program, as applicable to the target audience.
F. Personnel Monitoring 1. Personnel dosimetry monitoring (Facility-Specific) 2. Personnel contamination monitoring at electron and proton accelerator facilities Electron facilities typically will have a lower incidence of contamination than proton facilities due to the higher neutron flux produced by proton collisions.	Review the general dosimetry program if not covered in other training.
3. Locations (Facility-Specific) Discuss locations requiring personnel radiation exposure and contamination monitoring.	Review facility-specific information.

4. Jobs/tasks (Facility-Specific)

Jobs/tasks that may require personnel contamination monitoring include:

- Machining and welding of activated materials.
- Handling water used to cool accelerator components.
- Handling sealed sources suspected of leakage.
- Entering target rooms.
- Accidental releases.

VI. RADIOACTIVE WASTE ISSUES

A. Sources of Radioactive Waste

The radioactive waste from an accelerator facility tends to be mostly machine components or experimental equipment used in or near the particle beam. These components are often of copper, iron (steel), and aluminum. Other items or tasks contributing to radioactive waste are:

- Shielding blocks (iron, lead, or concrete).
- Coolant.
- Maintenance/modifications.
- Cleaning materials.

1. Shielding blocks (iron, lead, or concrete)

Shielding blocks are quite large and their highest activity is usually below the surface. Shielding blocks showing several rad/hr at the surface may have no removable (wipeable) surface contamination and can be stored without contamination problems. Whenever possible, shielding blocks should be stored for reuse where dose is not a problem.

2. Coolants

If possible, cooling water should be cleaned and recirculated/reused. The use of "pure" water minimizes the radioactivation problems caused by impurities.

Review facility-specific information.

It may be desirable to dispose of water before the tritium concentration becomes too high. Some possibilities for disposal are:

a. Sanitary sewer: Disposal through the sanitary sewer. This may be regulated by several agencies, such as DOE, NRC, EPA, and State and local water pollution control boards. Their regulations will set concentration limits and, perhaps, annual limits.

b. Evaporation: The water can be evaporated in engineered evaporation systems.

c. Solidification: The water can be used to make concrete for solidification of other liquid wastes.

d. Decay: Water from a small-volume, high concentration system could be transferred to a large-volume, low concentration system where it can decay safely.

Insert facility-specific radionuclides of concern.

e. Ion exchange resins and filters: These are used to remove impurities from recirculating cooling water systems and can accumulate radionuclides such as Be-7, Na-22, Mn-54, and Co-60.

3. Maintenance/modifications

Radioactive waste can be generated by maintenance and modification of beamline components. Waste from this source may include:

a. Compactables: Compactables such as rags, anticontamination clothing, surface coverings, etc.

b. Tools, equipment, components: Items that are no longer of use. These may consist of materials contaminated by the transfer of activated radioactive material to their surface or items that are radioactivated from being in the beamline.

Discuss facility-specific limits, as applicable.

4. Soils

Soils surrounding buried beam dumps may become activated. These can become classified as radioactive waste when facilities are modified or decommissioned.

B. Minimizing Radioactive Waste

EO-18 IDENTIFY methods to minimize radioactive waste at the facility. Ask participants for methods to minimize waste.

Because of the difficulty and cost in disposing of radioactive waste, special care should be taken to minimize waste generated.

Discuss pros and cons of saving or discarding material, decontamination, storage, reuse, etc.

- Avoid bringing unnecessary material into accelerator enclosures.
- Designate an area to store contaminated tools for reuse.
- Plan your work so that, whenever possible, construction and clean maintenance can be done in a clean area.
- Do not leave unnecessary tools and equipment in accelerator enclosures.
- Reuse items.

C. Mixed Waste

Mixed waste is waste that is classified as hazardous in accordance to the Environmental Protection Agency (EPA) AND is also radioactive. There is presently no approved method to dispose of mixed waste, and long-term storage is required.

1. Sources of mixed waste.

Common examples of waste materials at accelerators are:

- Lead (shielding, batteries, etc.).
- PCBs.
- Cadmium.
- Acids.
- Bases.
- Solvents and degreasers.

D. Minimizing Mixed Waste

- Use non-hazardous cleaning materials for decontamination.

- Segregate "radioactive only" from "hazardous only" at the source.

- Explore the use of non-hazardous materials.

Ask participants for methods to minimize mixed waste.

VII. ABNORMAL CONDITIONS

EO-19 IDENTIFY facility alarms and responses to abnormal conditions.

To properly deal with unexpected abnormal situations occurring in an accelerator facility, a well-thought-out responses program and personnel trained to execute the responses should be in place. Abnormal conditions may include:

Discuss the consequences of design basis accidents at the facility. Include facility-specific Emergency Action Levels and Protection Actions in accordance with the site hazard assessment.

A. Loss of Beam Containment (Facility-Specific).

Discuss facility-specific actions.

Discussion of potential cause of abnormal conditions.

B. Radiation Overexposure (Facility-Specific)

Discuss facility-specific actions.

C. Fires (Facility-Specific).

Discuss facility-specific actions.

Lesson Plan	Notes
D. Loss of Radioactive Material (Facility-Specific).	
Discuss facility-specific actions.	
E. Facility Alarms (Facility-Specific).	
Discuss facility-specific actions.	
F. Safety Assessment Document (SAD).	Discuss the consequences of design basis accidents at the facility. Include facility-specific Emergency Action Levels and Protection Actions in accordance with the site hazard assessment.
DOE Order 420.2C requires a SAD for accelerators. The SAD provides analysis of the potential accidents that can be experienced at a particular facility and outlines the accelerator's safety envelope.	Discuss the potential cause of abnormal conditions.
VIII. LESSONS LEARNED	Discuss lessons learned.
Previous incident reports.	

IX. REVIEW OF COURSE OBJECTIVES

The participant will be able to SELECT the correct response from a group of responses that verifies his/her ability to:

EO-01 IDENTIFY uses for accelerators.
EO-02 STATE the type(s) of accelerators at the facility.
EO-03 STATE type(s) of particles accelerated.
EO-04 DEFINE prompt radiation.
EO-05 DISCUSS the biological affects of radiation characteristics of accelerators.
EO-06 IDENTIFY prompt radiation sources at facility.
EO-07 DEFINE radioactivation.
EO-08 IDENTIFY activation sources at facility.
EO-09 IDENTIFY ancillary sources at facility.
EO-10 IDENTIFY activation products.
EO-11 IDENTIFY engineer and administrative controls at accelerator facilities.
EO-12 DESCRIBE each access mode at facility and access to beam and beam containment including interlocks and warning devices and system.
EO-13 DISCUSS site configuration control program.
EO-14 DISCUSS special radiological surveys and techniques.
EO-15 STATE purpose of initial entry survey.
EO-16 DISCUSS special instruments and measurement techniques.
EO-17 STATE site requirements for removing material from beam enclosure.
EO-18 IDENTIFY methods to minimize radioactive waste at the facility.
EO-19 IDENTIFY facility alarms and responses to abnormal conditions.

(Part 3 of 4)

Radiological Training for Accelerator Facilities

Student's Material

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

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Table of Contents

Page

COURSE MATERIALS 54
Course Goal 54
Target Audience 54
Description 54
Prerequisites 54
Length 55
Terminal Objectives 55
Enabling Objectives 55
Training Aids 55
Equipment Needs 56
Student Materials 56

I. HISTORY AND USES OF ACCELERATORS 57
A Definition 57
B Need for Accelerators 57
C The Development of the Accelerator 57
D Van de Graaff Generator 58
E Cockcroft-Walton Accelerator 58
F Linear Accelerators 58
G Lawrence and the Development of the Cyclotron 58
H Synchrotrons 59
I Colliders 59
J Purpose and Uses 60

II. FACILITY DESCRIPTION 60
A Types of Accelerators in Use at Facility (Facility-Specific) 60
B Types of Particles Accelerated at the Facility (Facility-Specific) 61
C Facility Layout and Description of Areas/Components (Facility-Specific) 61

III. RADIOLOGICAL CONCERNS 61
A Prompt Radiation 61
B Residual Radioactivation 64
C Ancillary Sources 67

IV. TYPES OF CONTROLS 68
A Engineered Controls 69
B Administrative Controls 70
C Accelerator Facility Access Modes (Facility-Specific) 71
D Configuration Control Program 72

V. MONITORING 73
A Qualification of Monitors 73
B Area Monitoring 73
C Prompt Radiation Monitoring 74
D Residual Radiation 74
E Environmental Monitoring 76
F Personnel Monitoring 76

VI. RADIOACTIVE WASTE ISSUES 77
A Sources of Radioactive Waste 77
B Minimizing Radioactive Waste 79
C Mixed Waste 79
D Minimizing Mixed Waste 80

VII. ABNORMAL CONDITIONS 80
A Loss of Beam Containment (Facility-Specific) 80
B Radiation Overexposure (Facility-Specific) 80
C Fires (Facility-Specific) 80
D Loss of Radioactive Material (Facility-Specific) 81
E Facility Alarms (Facility-Specific) 81
F Safety Assessment Document (SAD) 81

VIII. LESSONS LEARNED 81

DEPARTMENT OF ENERGY - COURSE PLAN

Course Goal:	Upon completion of this training, the student will have a basic understanding of the characteristics of accelerators and the precautions and safeguards needed for radiological safety while working in an accelerator facility.
Target Audience:	Individuals who have been assigned radiological duties (e.g., duties typically requiring radiological worker training or equivalent) in accelerator facilities.
Description:	This course illustrates and reinforces the skills and knowledge needed to provide personnel with an understanding of the characteristics of accelerators and the radiological safety precautions needed for working at an accelerator facility. Note: This lesson is not intended to be a requirement of all accelerator facilities but rather a resource to be used at the discretion of the facility training organization. Accelerator facilities may use any portion of this material. Note: Facility-specific information that requires each facility to input information is denoted as "Facility-Specific."
Prerequisites:	Training that is considered commensurate with facility-specific hazards.

Training which is considered commensurate with site-specific hazards. Radiological Worker I or II or the equivalent is recommended prior to receiving this accelerator facilities safety training. Completion of Module 1 of Volume 1 of DOE-HDBK-1019-93, reaffirmed 1999, *DOE Fundamentals Handbook, Nuclear Physics and Reactor Theory*, is also recommended.

Length: 2-4 hours (depending on facility-specific information).

Terminal Objectives: At the end of this course, the participant should be able to demonstrate a basic understanding of the characteristics of accelerators and the radiological precautions for working at an accelerator facility.

Enabling Objectives:

EO-01 IDENTIFY uses for accelerators.
EO-02 STATE the type(s) of accelerators at the facility.
EO-03 STATE type(s) of particles accelerated.
EO-04 DEFINE prompt radiation.
EO-05 DISCUSS the biological effects of radiation characteristic of accelerators.
EO-06 IDENTIFY prompt radiation sources at the facility.
EO-07 DEFINE radioactivation.
EO-08 IDENTIFY activation sources at the facility.
EO-09 IDENTIFY ancillary sources at the facility.
EO-10 IDENTIFY activation products.
EO-11 IDENTIFY engineered and administrative controls at accelerator facilities and personal protective equipment.
EO-12 DESCRIBE each access mode at the facility and access to beam and beam containment including interlocks and warning devices and systems.
EO-13 DISCUSS site configuration control program.
EO-14 DISCUSS special radiological surveys and techniques.
EO-15 STATE purpose of initial entry survey.
EO-16 DISCUSS special instruments and measurement techniques.
EO-17 STATE site requirements for removing material from beam enclosure.
EO-18 IDENTIFY methods to minimize radioactive waste at the facility. (Facility-Specific)
EO-19 IDENTIFY facility alarms and responses to abnormal conditions. (Facility-Specific)

Training Aids: Overhead transparencies (may be supplemented or substituted with updated or Facility-Specific information).

Equipment Needs:

- o Overhead projector.
- o Screen.
- o Flip chart.
- o Markers.

Student Materials: Student's Materials.

Lesson Plan Notes

II. HISTORY AND USES OF ACCELERATORS

D. Definition

Accelerators are devices employing electrostatic or electromagnetic fields to input kinetic energy to molecules, atomic or subatomic particles. This training is provided because accelerators also are capable of creating a radiological area and other radiological hazards.

B. Need for Accelerators

In the early 1900s, radioactive particles could be obtained only from materials found in nature. The studies that physicists wanted to perform required both higher intensities and higher energies than were obtainable from the natural sources. The ability to vary energy and intensity to suit a particular experiment was also desirable.

In the 1930s, scientists began to build machines that produced the needed degree of control. These machines were called accelerators.

C. The Development of the Accelerator

The earliest accelerators were simple vacuum tubes in which electrons were given an increase in energy by the voltage difference between two oppositely charged electrodes.

1. Acceleration

   The acceleration of the electron by this electrical force also increases the energy of the electron.

2. Electron volt

   The amount of acceleration is determined by the potential difference measured in volts (V) in this electrical field.

   One electron volt (eV) is the energy gained by an electron accelerated through a potential difference of one volt.

   An electron accelerated across a gap by means of a 10,000 volt, or 10 kilovolt (kV), potential difference is said to have gained 10,000 electron volts (10 keV) of energy after crossing the gap.

D. Van de Graaff Generator

One of the first machines to produce laboratory- accelerated particles was the Van de Graaff generator.

1. Operation
The Van de Graaff consists of a polished metal sphere and a moveable belt. The function of the belt is to carry an electrical charge up to the sphere where it is stored. This process can be continued until a very high potential is developed in the sphere.

2. Early generators
In 1929, Van de Graaff built a pilot machine capable of generating 80,000 volts. In 1931, a 1.5 million-volt (MeV) machine was built at Princeton.

3. State of the Art
A 25 MeV machine was built and operated at Daresbury Laboratory in the United Kingdom.

E. Cockcroft-Walton Accelerator

In 1932 in England, John D. Cockcroft and Ernest T.S. Walton constructed what is called a linear accelerator using a high-voltage source to accelerate protons through 700,000 volts (700 keV).

F. Linear Accelerators

From the first simple machines (Cockcroft-Walton and Van de Graaff machines) evolved the larger and more elaborate machines. The modern example of this type of accelerator is the linear accelerator, a sophisticated machine used in many scientific and medical applications.

G. Lawrence and the Development of the Cyclotron

The great breakthrough in accelerator technology came in 1930 with Ernest O. Lawrence's invention of the cyclotron.

1. Operation

In the cyclotron, magnets guide the particle along a spiral path, allowing a single electric field to apply many cycles of acceleration.

2. Prototype

Soon unprecedented energies were achieved, and the steady improvement of Lawrence's simple machine has led to today's synchrotrons, whose endless circular flight paths allow particles to gain huge energies by passing millions of times through the electric fields that accelerate them.

H. Synchrotrons

A synchrotron accelerates particles using electric fields over and over in a circular path. Magnetic fields are used to bend the particles' trajectories and keep them moving in a circle. The accelerated particles lose energy rounding the curves, so energy must be continuously supplied. The beam is extracted heading toward targets and detectors.

I. Colliders

Until 30 years ago, all accelerators were so-called fixed-target machines in which the speeding particle beam was made to hit a stationary target of some chosen substance.

In the early 1960s, physicists had gained enough experience in accelerator technology to be able to build colliders in which two carefully controlled beams are made to collide with each other at a chosen point. The beams for colliders may come from two synchrotrons or two linear accelerators.

J. Purpose and Uses

Accelerators were originally designed to study (research) the structure of matter. Accelerators today are used not only for basic research purposes, but for many other applications such as:

- Production of radioisotopes, such as tritium.
- Generation of bremsstrahlung for radiography and radiation therapy.
- Induction of fusion.
- Pumping for lasers.
- Detoxification of hazardous waste.
- Actinide transmutation.
- Production of synchrotron radiation.
- Sterilization of food and surgical equipment.
- Medical radiation therapy.

II. FACILITY DESCRIPTION

A. Types of Accelerators in Use at Facility (Facility-Specific)

Electrostatic accelerators
- Cockcroft-Walton.
- Van de Graaff, Tandem Van de Graaff.

Linear accelerators (Linac)
- Resonant cavity (standing wave).
- Traveling wave.

Cyclic accelerators
- Synchrotron.
- Cyclotron.
- Betatron.

Lesson Plan Notes

E. Types of Particles Accelerated at the Facility (Facility-Specific)

F. Facility Layout and Description of Areas/Components (Facility-Specific)

- Injectors.
- Target areas.
- Experimental areas.
- Beamlines.
- Control room.
- Shielding structures.

III. RADIOLOGICAL CONCERNS

A. Prompt Radiation

Prompt radiation includes the accelerated particle beam and the radiation produced when the beam interacts with matter or changes direction. It is only present when a beam is operating or being accelerated.

1. Primary beam

The primary beam consists of accelerated charged particles prior to any interactions.

The primary beam is the most intense form of radiation present at an accelerator facility and is made inaccessible to personnel through engineering design and administrative controls.

2. Secondary beam

Secondary beam is produced by interaction of the primary beam with targets or beamline components. The secondary beam may consist of:

- Electromagnetic radiation.
- Neutrons.
- Charged particles.
- Other elementary particles.

3. Skyshine

Skyshine is the radiation scattered from air molecules. Accelerator-produced skyshine is usually neutron radiation, scattered after emerging more or less vertically from the shielded enclosure. It can cause elevated radiation fields at ground level considerable distances from the source.

Due to typical facility design, photon skyshine is usually less of a problem but is a consideration, particularly where radioactive materials are stored.

5. Electromagnetic radiation

a. <u>Bremsstrahlung</u>: (photons emitted through the deceleration of charged particles passing through matter).

b. <u>Electromagnetic cascades</u>: (multiple photons emitted through high-energy interactions).

c. <u>Synchrotron radiation</u>: (photons emitted as the charged particles are accelerated in a curved path).

Lesson Plan | Notes

5. Neutrons

Neutrons can be produced through nuclear interactions of the primary or secondary beam with matter. They can also be produced by interaction of high-energy photons about with matter (photoneutron reaction). The photoneutron reaction typically requires photons with energy in excess of 10 MeV.

e. Neutron radiation is a concern within any area where the beam can interact with physical objects.

f. Location of potential sources of neutron radiation exposure. (Facility-Specific).

6. Muons

Muons are particles that are physically similar to electrons, but about 200 times heavier. Like electrons, they can be positively or negatively charged

c. Muons are produced by several mechanisms and require photon energies greater than 212 MeV or proton energies greater than 140 MeV.

d. Muons are not usually seen in significant amounts at machines with energies less than 1 giga electron-volt (GeV).

g. Muons travel mainly in the direction of the beam that produced them with very little deviation from the beam path. They are a concern directly downstream of targets, beam dumps, etc. Muons are ionizing particles and can deliver a very high dose.

h. Muons lose energy only through ionization and are very penetrating. Large amounts of earth or steel are typically used to shield muons.

7. Facility-Specific

Identify facility-specific prompt radiation sources.

B. Residual Radioactivation

The process by which materials become radioactive is commonly referred to as "radioactivation" or simply "activation." Generally, energies above 10 MeV are needed to activate materials for particles other than neutrons.

1. Residual radioactivity

Activated materials emit radiation from radioactive decay after shut-off of the beam.

4. Contaminated material versus activated material.

Contaminated materials are items with fixed or removable surface contamination.

Activated material is radioactive material dispersed throughout the item and is not removable except through some type of destructive means as discussed below.

a. Activated materials normally do not present a potential loose contamination hazard except during activities such as:

- Grinding.
- Burning.
- Machining.
- Handling coolant water filters.

Target spallation may also create contamination without any of the above (or similar) physically destructive operation applied.

b. Activated materials are normally controlled based on the external radiation dose rate.

3. Activated materials

All materials located within an accelerator enclosure have the potential to be radioactivated if subjected to primary or secondary beams.

Materials that may become radioactive include:

- Any material within the accelerator enclosure.
- Beamline components.
- Air.
- Cooling liquids and working fluids.

4. Beamline components

Beamline components may become radioactive depending on:

- Nature of the material.
- Proximity to the beam.
- Beam characteristics.

Items that intercept a portion of the beam are most likely to be activated and contaminated. Among those items that have the highest probability for activation are:

- <u>Targets</u>: devices to intercept a portion of the beam for purposes of producing secondary beams.
- <u>Beam dumps or stops</u>: used to absorb the beam.
- <u>Collimators and scrapers</u>: used to remove unwanted diffuse "halo" that often exists surrounding the central beam.
- <u>Septa and other magnets</u>: used to align and direct beams.
- <u>Cavities and beamline</u>: the beamline piping and items such as resonating cavities, detectors, etc.

5. Air

Air, dust, and other gases in the accelerator enclosure may be activated. Typically, the activation products are short-lived gaseous radionuclides of the elements in the air or particulate, in the case of dust particles. An example is Oxygen-15 from Nitrogen-14. Most of these activation radionuclides have a short half-life (the time it takes for one-half of the atoms to decay).

6. Liquids

c. Cooling water: used for cooling beamline components (activation products such as tritium (H-3), beryllium (Be-7) and possible pipe wear products or erosion of the pipe surfaces).

d. Oil in vacuum pumps (beam line components).

c. Cryogenic fluids: liquid helium and nitrogen are used frequently to cool components.

7. Facility-Specific

Facility should cover items that routinely become activated due to accelerator operation.

8. Contamination

Materials and activities that could create contamination concerns.

e. Surface coating: such as paint, oxidation, and rust may present a contamination problem. Such coatings may be easily removable and may be present in areas not commonly accessed, such as beam dump vaults.

f. Compounds: such as grease, sealants, gaskets, and anti-seize coatings may be activated depending on their composition. Prior to maintenance, these compounds should be chosen carefully to minimize the production of contamination if possible. These materials may not be accessible until after components are disassembled; therefore, the need for carefully planned maintenance activities involving such compounds should be highlighted.

g. Impurities: Impurities in cooling water systems can be a source of contamination. This source may be found in a filter/resin media system.

h. Activities: (Facility-Specific) routine work areas where contamination control must be considered:

- Machining of radioactive materials.
- Cooling water filters.
- Accessing beamline.
- Maintenance.
- Target removal.
- Etc.

C. Ancillary Sources

Accelerators employ devices to impart energy to particles or redirect them during the acceleration process. These devices may emit ionizing radiation while they are operating.

1. Klystrons

Klystrons provide power to accelerate charged particles. They emit X-rays during operation.

2. Radiofrequency cavities

These devices accelerate charged particles using electromagnetic fields. Electrical discharges within the RF cavity cause photon (ionizing radiation) emission.

3. Electrostatic separators/Septa

These devices split a particle beam into two beams using static electric fields. The high voltages associated with these devices cause electrons to accelerate in the vacuum within the beamline. They emit X-rays. Septa are also a high source of activation and residual radiation.

4. Facility-Specific

Location of facility-specific ancillary sources.

IV. TYPES OF CONTROLS

Controls are used at accelerator facilities to protect personnel from exposure to ionizing radiation and other hazards including:

- Electrical.
- Mechanical.
- Cryogenic.
- Non-ionizing radiation.

The design of an effective safety program incorporates a combination of:

- Engineered controls.
- Administrative controls.
- Personal protective equipment, e.g., respirators, protective clothing, etc.

However, per 10 CFR 835.1001(c), the primary methods used should be physical design features. Administrative controls and procedural requirements should be employed only as supplemental methods to control radiation exposure.

A. Engineered Controls

Engineered controls include equipment and structures (passive or active) designed to protect personnel from hazards.

1. Passive engineered controls

   Once installed, passive engineered controls require no further action to perform their intended function. Passive engineered controls may include:

   a. Radiation shielding: such as concrete blocks, iron plates, lead bricks and earth berms.

   b. Barriers: such as fences, locked gates, and doors.

   c. Facility-Specific: facility-specific passive engineered controls.

2. Active engineered controls

   Active engineered controls include devices that sense changing conditions and can trigger a safety action.

   b. Safety interlock devices.

      - Area radiation monitors.
      - Access sensors, magnetic and mechanical.
      - "Crash" or "scram" buttons.

   b. Facility-specific: Facility-specific active engineered control devices.

B. Administrative Controls.

Programs and activities which personnel must implement to provide protection from hazards.

1. Search and secure (sweep) procedures.

   These are procedures used to verify that no personnel remain in a beamline enclosure when it is being prepared to receive beam.

2. (Facility-Specific) search procedures.

3. Controlled access procedures (including key controls).

   Procedures that allow personnel to access a beamline enclosure while it remains interlocked. There is no physical search of the area before the beam is restored.

4. (Facility -Specific) controlled access procedures.

5. Radiological work permits (RWPs).

   RWPs provide written documentation of job descriptions, radiological conditions, and the required protective controls.

6. Configuration control procedures.

   Procedures to ensure that important information about the configuration of a facility is accurate and that the configuration retains its functional purpose.

7. Radiological monitoring programs.

   Provide assurance that the accelerator facility operates within the radiological safety design specifications and ALARA goals.

8. Warning indicators.

   - Status lights.
   - Alarms.

C. Accelerator Facility Access Modes (Facility-Specific)

The status or mode of accelerator enclosures regarding accessibility are covered below. Access modes change with the beam status.

1. Normal or open access mode

   Beam area is not interlocked and beam cannot operate. Access to these areas is unrestricted after a radiation survey to identify and isolate areas of activation or contamination.

2. Search & secure mode

   Operators physically search enclosures prior to beam operation to ensure that no personnel remain in the enclosure when it is secured for operation.

3. Controlled access mode

   a. <u>Beam area</u>: Beam area has been searched and secured and remains interlocked, however, beam cannot operate.

      Limited personnel access is allowed. There is no search of area following the access.

   b. <u>Procedure</u>: Controlled access procedure (Facility-Specific).

Lesson Plan Notes

4. Test mode

Certain devices, (e.g., magnets) may be energized to allow testing. Limited personnel may access but must be aware of hazardous conditions (e.g. electrical power).

5. Exclusion mode

Beam may be present. No access is allowed.

D. Configuration Control Program

The facility design must continue to meet its intended function while providing for adequate personnel safety. Configuration control ensures that only authorized changes are made and that any changes made continue to provide adequate personnel safety.

1. Elements of a program

Configuration control programs for accelerator facilities include:

- Inventory and labeling of controlled devices.
- Periodic inspections.
- Procedures for change and/or restoration of configuration.
- Testing to verify proper configuration.

2. Structures and equipment.

These must be maintained in a specific configuration to perform the desired safety function.

Examples include:

- Radiation shielding.
- Magnets.
- Stops.
  Detectors.
- Interlocks and access system wiring.

3. (Facility-Specific) configuration control procedures.

V. MONITORING

Monitoring refers to the checking, testing, and surveying of individuals, work areas, materials and equipment for ionizing radiation and radioactivity.

Monitoring for radiation at accelerators can be complicated. Special techniques and instrumentation may be necessary due to the existence of:

- Mixed radiation fields (photons, protons, neutrons, etc.).
- Pulsed beams.
- Very high energy radiation.
- High intensities of radiation (dose rates).
- Magnetic and RF fields.

A. Qualification of Monitors

Monitoring is only performed by Radiological Control Personnel or others who are specifically trained and qualified to perform monitoring.

B. Area Monitoring

Monitoring of areas at accelerator facilities refers to monitoring for radiation and contamination using fixed and portable instruments. Monitoring may include measuring for:

- Prompt radiation.
- Residual radiation.

and includes:

- Work areas.
- Surfaces.
- Water.
- Air.
- Non-work areas outside of enclosures.

C. Prompt Radiation Monitoring

Prompt radiation monitoring is to ensure radiation levels outside of accelerator facilities are maintained below regulatory limits to workers and the general public, and as a means to detect deficiencies in beam containment.

1. Instrumentation

Prompt radiation surveys may utilize fixed and portable instruments.

2. Pulsed radiation

Prompt pulsed radiations must be measured with specialized survey instruments. Ion chambers are typically used.

3. Neutron radiation.

Neutron monitoring is complicated and should be performed by an individual qualified to perform neutron surveys.

D. Residual Radiation

Radioactive materials may be found at accelerator facilities in the form of:

- Removable contamination.
- Fixed contamination.
- Activated materials.
- Volume contamination.

1. Residual radiation monitoring

Residual radiation is typically monitored with portable instruments and contamination swipes. Types of monitoring may include:

- Work areas.
- Items/materials.
- Operational systems.

Lesson Plan | Notes

2. Monitoring instruments

   Special instruments may be needed for monitoring residual activity in materials depending on:

   - Nature of material.

   - Physical form (i.e., liquids).

3. Work areas

   Types of work area surveys include:

   - Radiation dose rate surveys.

   - Loose surface contamination surveys.

   - Air sampling, including continuous air monitoring.

4. Items/materials monitoring (Facility-Specific)

   The purpose of monitoring materials is to ensure radioactive materials are identified and controlled within controlled areas. All items/materials must be surveyed prior to removal from areas of potential activation/contamination.

   Typically this includes any material inside the beam enclosures, targets and shielded structures.

5. Cooling water and other systems.

   Typical monitoring may include:

   - Sampling component cooling water.

   - Monitoring filter media.

Lesson Plan | Notes

E. Environmental Monitoring

Environmental sampling/monitoring may include:

- Prompt radiation levels (neutrons, skyshine, muons, etc.).
- Radiation levels at site boundary from storage areas, etc.
- Sampling of exhausted air from beam housings.
- Surface/ground water (on and off site).
- Monitoring of radiation levels at site boundary.
- Soil/vegetation/deposition near liquid discharges and air exhaust.

F. Personnel Monitoring

2. Personnel dosimetry monitoring (Facility-Specific)

2. Personnel contamination monitoring at electron and proton accelerator facilities

   Electron facilities typically will have a lower incidence of contamination than proton facilities due to the higher neutron flux produced by proton collisions.

5. Locations (Facility-Specific)

   Discuss locations requiring personnel radiation exposure and contamination monitoring.

4. Jobs/tasks (Facility-Specific)

Jobs/tasks that may require personnel contamination monitoring include:

- Machining and welding of activated materials.
- Handling water used to cool accelerator components.
- Handling sealed sources suspected of leakage.
- Entering target rooms.
- Accidental releases.

VI. RADIOACTIVE WASTE ISSUES

A. Sources of Radioactive Waste

The radioactive waste from an accelerator facility tends to be mostly machine components or experimental equipment used in or near the particle beam. These components are often of copper, iron (steel), and aluminum. Other items or tasks contributing to radioactive waste are:

- Shielding blocks (iron, lead, or concrete).
- Coolant.
- Maintenance/modifications.
- Cleaning materials.

1. Shielding blocks (iron, lead, or concrete)

Shielding blocks are quite large and their highest activity is usually below the surface. Shielding blocks showing several rad/hr at the surface may have no removable (wipeable) surface contamination and can be stored without contamination problems. Whenever possible, shielding blocks should be stored for reuse where dose is not a problem.

2. Coolants

If possible, cooling water should be cleaned and recirculated/reused. The use of "pure" water minimizes the radioactivation problems caused by impurities.

It may be desirable to dispose of water before the tritium concentration becomes too high. Some possibilities for disposal are:

f. Sanitary sewer: Disposal through the sanitary sewer. This may be regulated by several agencies, such as DOE, NRC, EPA, and State and local water pollution control boards. Their regulations will set concentration limits and, perhaps, annual limits.

g. Evaporation: The water can be evaporated in engineered evaporation systems.

h. Solidification: The water can be used to make concrete for solidification of other liquid wastes.

i. Decay: Water from a small-volume, high concentration system could be transferred to a large-volume, low concentration system where it can decay safely.

j. Ion exchange resins and filters: These are used to remove impurities from recirculating cooling water systems and can accumulate radionuclides such as Be-7, Na-22, Mn-54, and Co-60.

3. Maintenance/modifications

Radioactive waste can be generated by maintenance and modification of beamline components. Waste from this source may include:

c. Compactables: Compactables such as rags, anticontamination clothing, surface coverings, etc.

d. Tools, equipment, components: Items that are no longer of use. These may consist of materials contaminated by the transfer of activated radioactive material to their surface or items that are radioactivated from being in the beamline.

4. Soils

Soils surrounding buried beam dumps may become activated. These can become classified as radioactive waste when facilities are modified or decommissioned.

B. Minimizing Radioactive Waste

Because of the difficulty and cost in disposing of radioactive waste, special care should be taken to minimize waste generated.

- Avoid bringing unnecessary material into accelerator enclosures.
- Designate an area to store contaminated tools for reuse.
- Plan your work so that, whenever possible, construction and clean maintenance can be done in a clean area.
- Do not leave unnecessary tools and equipment in accelerator enclosures.
- Reuse items

C. Mixed Waste

Mixed waste is waste that is classified as hazardous in accordance to the Environmental Protection Agency (EPA) AND is also radioactive. There is presently no approved method to dispose of mixed waste, and long-term storage is required.

1. Sources of mixed waste.

Common examples of waste materials at accelerators are:

- Lead (shielding, batteries, etc.).
- PCBs
- Cadmium.
- Acids.
- Bases.
- Solvents and degreasers.

D. Minimizing Mixed Waste

- Use non-hazardous cleaning materials for decontamination.

- Segregate "radioactive only" from "hazardous only" at the source.

- Explore the use of non-hazardous materials.

VII. ABNORMAL CONDITIONS

To properly deal with unexpected abnormal situations occurring in an accelerator facility, a well-thought-out responses program and personnel trained to execute the responses should be in place. Abnormal conditions may include:

A. Loss of Beam Containment (Facility-Specific).

Discuss facility-specific actions.

B. Radiation Overexposure (Facility-Specific)

Discuss facility-specific actions.

C. Fires (Facility-Specific).

Discuss facility-specific actions.

Lesson Plan | Notes

D. Loss of Radioactive Material (Facility-Specific).

Discuss facility-specific actions.

E. Facility Alarms (Facility-Specific).

Discuss facility-specific actions.

G. Safety Assessment Document (SAD).

DOE Order 5480.25 requires a SAD for accelerators. The SAD provides analysis of the potential accidents that can be experienced at a particular facility and outlines the accelerator's safety envelope.

VIII. LESSONS LEARNED

Previous incident reports.

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(Part 4 of 4)

Radiological Training for Accelerator Facilities

Handouts

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

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Glossary

Accelerator: A device employing electrostatic or electromagnetic fields to input kinetic energy to molecules, atomic, or subatomic particles. This training is provided because accelerators are capable of creating a radiological area or other radiological hazards.

Access control system: Engineered or administrative systems that manage radiation dose to personnel by limiting personnel entry.

Actinide Transmutation: Transformation of actinides through neutron activation.

Activity: The rate at which a source emits radiation is called its activity. Activity is measured in terms of the number of disintegrations that take place every second. The unit for activity used at DOE sites is the curie (Ci). One curie is equal to 37 billion (3.7×10^{10}) disintegrations per second.

Annual Limit on Intake (ALI): Means the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. (see 10CFR 835)

Attenuation: The process by which a beam of radiation is reduced in intensity when passing through some material. It is the combination of absorption and scattering processes and leads to a decrease in flux intensity.

Beam: A flow of electromagnetic or particulate radiation that is either collimated and generally unidirectional, or divergent from a small source but restricted to a small solid angle.

Beam scrapers: Beam scrapers remove particles that have wandered from the central area of the beam.

Bremsstrahlung: Secondary photon radiation produced by deceleration of charged particles passing through matter.

Collider: An accelerator in which two opposed beams of particles collide head-on.

Continuous Air Monitor (CAM): Instrument that continuously samples and measures the levels of *airborne radioactive materials* on a "real time" basis and has alarm capabilities at preset levels.

Cryostat: An instrument or device that maintains low temperature for superconducting magnets.

Cyclotron: A cyclic accelerator in which the charged particles spiral outward from the center of the machine as they gain energy.

Glossary - Continued

Decommissioning: The process of closing and securing a nuclear facility, or nuclear materials storage facility, so as to provide adequate protection from radiation exposure and to isolate radioactive contamination from the human environment.

Depleted Uranium: Uranium having a percentage of uranium-235 smaller than the 0.7% found in natural uranium.

Derived Air Concentration (DAC): The airborne concentration that equals the ALI divided by the volume of air breathed by an average worker for a working year of 2,000 hours (assuming a breathing volume of 2,400 m^3).

Detector: Any device that can detect the presence of an energetic electromagnetic radiation particle or nuclear fragment and measure one or more of its properties.

Electromagnetic Radiation: A traveling wave motion resulting from changing electric or magnetic fields. Familiar electromagnetic radiations range from *X-rays* and *gamma rays* of short wavelength, through the ultraviolet, visible and infrared regions, radar and radio waves of relatively long wavelength.

Enclosed Beam: All possible X-ray beam paths are fully contained in protective enclosures so that no part of the body can intercept the beam during normal operation.

Electron volt: A unit of energy equivalent to the energy gained by an electron in passing through a potential difference of one volt.

Exclusion Area: Any area to which access is prohibited for the purposes of protection of individuals.

Fail-Safe: A design feature built into a system or system component so that the most likely mode of failure causes the production of X-rays to be turned off. If fail-safe design is not possible or cost-effective, the system or system component should be designed so that no single failure will cause unsafe operation.

Half-life: The time it takes for one-half of the radioactive atoms in a sample to decay.
Interlock: A safety device that automatically renders an area safe from prompt radiation when the device is actuated.

Linear accelerator: A device that accelerates charged particles along a straight line.

Mixed Waste: Waste containing both radioactive and hazardous components as defined by the Atomic Energy Act and the Resource Conservation and Recovery Act, respectively.

Muon: An elementary particle apparently identical to the electron except for being 200 times heavier.

Glossary - Continued

Neutron: Elementary particle with a mass approximately the same as that of a hydrogen *atom* and electrically neutral.

Nucleus: The small, central, positively charged region of an *atom* that carries essentially all the mass.

Pion: A cosmic particle with a mass about 273 times that of an *electron* and a half-life of 2/100,000,000 (2×10^{-8}) of a second. Positive, negative, and neutral pions exist.

Primary Beam: *Radiation* that passes through the window, aperture, cone, or other collimating device of the source housing. Sometimes called *useful beam*.

Prompt radiation: Radiation resulting from the accelerator beam or the interaction of the accelerator beam with surrounding matter that ceases shortly after the beam is removed. Activation products and area contamination are not considered prompt radiation.

Proton: An elementary nuclear particle with a positive electric charge and an atomic weight of approximately one.

Radiation: Radiation refers to the emission and propagation of waves or particles through matter or space. Matter absorbs energy from radiation. In a microwave oven, for example, food absorbs energy from microwave radiation and is heated and cooked.

Radiation alarm system: A system providing notification, including activation of a radiation warning system, that a radiation condition exists that exceeds preset limits. An alarm system may initiate mitigating action.

Radiation warning light: A system that alerts personnel to a potential or actual change in the radiation level in a working environment. A warning system does not initiate mitigating actions.

Radioactivation or Activation: The process of producing a radioactive material by bombardment with neutrons, protons, or other nuclear particles.

Redundancy: Duplication or repetition of elements in electronic or mechanical equipment to provide alternative functional channels in case of failure.

Scattered Radiation: Radiation that, during passage through matter, has been deviated in direction. It may have been modified also by a decrease in energy.

Scram switch: An interlock that is intended for emergency use only. Scram switches are usually placed within exclusion areas where personnel may be caught during pre-start-up or actual operations.

Search: (This is commonly referred to as a sweep.) A physical inspection carried out under controlled conditions to ensure that no personnel are left inside exclusion areas.

Glossary - Continued

Septa: An area associated with an accelerator beam line where the beam is split into two or more beams, normally through the use of magnets. This area is prone to radioactivation due to the interaction of the beam with structural materials.

Spectra: A visual display, a photographical record, or a plot of the distribution of the intensity of radiation at a given kind as a function of its wavelength, energy, frequency, momentum, mass, or any related quantity.

Spallation: A term used to denote a nuclear reaction induced by high-energy bombardment and involves the ejection of two or more particles.

Superconductivity: The ability of some materials to carry an electric current with no power loss, owing to the complete absence of electrical resistance. To date, superconductivity has been found only in a few metals and alloys and at very low temperatures.

Synchrotron: An accelerator in which the energy of charged particles is increased as they travel around a circular orbit of fixed radius.

Useful Beam: *Radiation* that passes through the window, aperture, cone, or other collimating device of the source housing. Sometimes called *primary beam*.

Volt: The term potential difference symbolized by V is defined as the work per unit charge done in moving a charge from one point to the other.

CONCLUDING MATERIAL

Review Activities:

DOE
Ops Offices

NNSA
AL
HS
CH
EM
ID
SC
NV
SA
OR
LM
RL
NE
SR
NS
PR

Area/Site Offices
Ames
Argonne
Berkeley
Brookhaven
Carlsbad
Fermi
Kansas City
Los Alamos
Oak Ridge Site Office
Princeton
SLAC
Thomas Jefferson
West Valley
Y-12

National Laboratories
Ames
ANL
BNL
FNAL
LBNL
ORNL
PPPL
SLAC
TJNAL

Preparing Activity:

DOE HS-11