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DOE-HDBK-1145-2001
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DOE STANDARD

Radiological Safety Training for Plutonium Facilities



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

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Radiological Safety Training for Plutonium Facilities
DOE–HDBK–1145–2001
Program Management Guide

Foreword

This Handbook describes an implementation process for training as recommended in Implementation Guide G441.1-12, *Radiation Safety Training Guide*, and as outlined in DOE-STD-1098-99, *DOE Radiological Control* (the Radiological Control Standard – RCS). The Handbook is meant to assist those individuals within the Department of Energy, Managing and Operating contractors, and Managing and Integrating contractors identified as having responsibility for implementing training required by Title 10 Code of Federal Regulations Part 835 *Occupational Radiation Protection* (10 CFR 835) and training recommended by the RCS. This training is intended for instructors to assist in meeting the training requirements of 10 CFR 835. While this Handbook addresses many requirements of 10 CFR 835 Subpart B, it must be supplemented with facility-specific information to achieve full compliance.

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

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

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

Overheads — This part contains overhead transparencies for instructor use, corresponding to the Instructor's Guide.

Student's Guide — This part is based on the Instructor's Guide, but has a blank space for students to write notes in place of the instructor's notes.

Handouts — This part contains several student handouts which provide supporting information for various modules.

This training material is targeted for individuals with demonstrated knowledge and skills in radiological protection and who have successfully completed an approved professional development program for training instructors. On-the-job experience at the facility is also required.

This Handbook was produced in Microsoft Word and has been formatted for printing on an HP 4M (or higher) LaserJet printer. Overheads were produced in PowerPoint. Copies of this Handbook may be obtained from either the DOE Radiation Safety Training Home Page Internet site (<http://tis.eh.doe.gov/whs/rhmwp/rst/rst.htm>) or in PDF format from the DOE Technical Standards Program Internet site (<http://tis.eh.doe.gov/techstds/>). Documents downloaded from the DOE Radiation Safety Training Home Page Internet site may be manipulated using the software noted above.

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Part 1 of 5

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Program Management Guide



**U.S. Department of Energy
Office of Environment, Safety & Health
Office of Worker Protection Policy and Programs**

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Introduction

Purpose and Scope

This program management guide describes the proper implementation standard for core training as outlined in the *DOE Radiological Control (RadCon) Standard*. The management guide is to assist those individuals, both within the Department of Energy (DOE), management and integrating (M&I) contractors, identified as having responsibility for implementing the core training of the *DOE Radiological Control (RadCon) Standard*.

Management Guide Content

The management guide is divided into the following sections:

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

Compliance Requirements

The DOE training materials for Radiological Safety Training for Plutonium Facilities reflect the requirements identified in 10 CFR 835-Subpart J, *Radiation Safety Training*, and recommendations identified in the DOE Implementation Guide G441.12, *Radiation Safety Training*, and in the *DOE Radiological Control Standard*. When implemented in its entirety and supplemented as noted with appropriate facility-specific information, this guide provides an acceptable method to meet the requirements of 10 CFR 835-Subpart J for radiation safety training for individuals in plutonium facilities.

However, it is incumbent on management of each facility to review the content of this Guide against the radiological hazards present to ensure that the training content is appropriate to each individual's prior training, work assignments, and degree of exposure to potential radiological hazards.

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Introduction (continued)

Organizational Relationships

The DOE Office of Environment, Safety, and Health’s Office of Worker Protection Policy and Programs (EH-52) is responsible for approving and maintaining radiation protection training materials. An oversight group consisting of representatives from Programs and Operations Offices and the major contractors will review comments and recommend program changes to EH.

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.

Instructional Materials Development

Target Audience

Course instructional materials are developed for specific employees who are responsible for knowing or using the knowledge or skills for each course. With this in mind, the participant should never ask, “Why do I need to learn this?” However, this question is often asked when the participant cannot apply the content of the program. It is the responsibility of management to select and send workers to training who need the content of the program. When workers can benefit from the course, they can be motivated to learn the content and apply it on their jobs. Care should be taken to ready 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.

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Instructional Materials Development (continued)

Prerequisites

A background and foundation of knowledge help the trainee learn 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 are 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, or the instructor to have this misunderstanding.

Workers who do not possess the necessary prerequisites should not register for a course. Those who do not qualify may be denied the training.

Training Materials

Training materials for the program consist of lesson plans, study guides, training aids, handouts, and in some cases, videos. The core training content should be presented in its entirety. Overhead transparencies are provided in support of the core training content, which are provided to the students at the close of training. These may be supplemented or substituted with updated or site-specific information.

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.

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 core material; each site is responsible for establishing such a method.

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Instructional Materials Development (continued)

Training Delivery

Sites are encouraged to expand per provisions in the RadCon Standard and enhance the training materials through advanced training technologies. Computer-based training and multimedia are just a sample of such technologies.

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 must 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 must know how to correctly perform their duties and why they are doing them. They must know how their actions influence other workers' responsibilities. Because workers' actions are so critical to their own safety and the safety of others, their trainers must be of the highest caliber. The technical instructor must thoroughly understand all aspects of the subjects being taught and the relationship of the subject content to the total facility. Additionally, the instructor must have the skills and knowledge to employ the instructional methods and techniques that will enhance learning and successful job performance. While the required technical and instructional qualifications are listed separately, it is the combination of these two factors that produces a qualified technical instructor.

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

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Training Program Standards and Policies (continued)

Technical Qualifications

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

- The trainees being instructed
- The subject being presented

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

TARGET AUDIENCE	SUBJECT TO BE TAUGHT	INSTRUCTOR TECHNICAL QUALIFICATIONS
Radiation Protection Technicians	Plan-specific radiation protection instruments, systems, and procedures	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, Nuclear Regulatory Commission, or other government license or certification; vendor or facility certification; and, most importantly, job experience. To maintain technical competence qualification, a technical instructor should continue to perform satisfactorily on the job and participate in continuing technical training.

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Training Program Standards and Policies (continued)

**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 at the successful completion of an approved professional development program for training instructors. The program should contain theories and practices of instructional skills and techniques; adult learning; and planning, conducting, and evaluating classroom, simulator, laboratory, and on-the-job training activities.

Illustrated talks, demonstrations, discussions, role playing, case studies, coaching, and individual projects and presentations should be used as the principal instructional methods for presenting the instructional training program. Each instructional method should incorporate the applicable performance-based principles and practices. Every effort should be made to apply the content to actual on-the-job experience or to simulate the content in the classroom/laboratory. The appropriate methodology required to present the instructional content will indicate a required level of instructional qualification and skill.

Current instructors' training, education, and job performance should be reviewed to determine their training needs for particular courses. Based on this review, management may provide exemptions based on demonstrated proficiency in performing technical instructors' 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.

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Training Program Standards and Policies (continued)

**Instructional Capability
and Qualifications
(continued)**

- Effectively communicate, verbally and nonverbally, lessons to enhance learning.
 - Invoke student interaction through questions and student activity.
 - Respond to students' questions.
 - Provide positive feedback to students.
 - Use appropriate instructional materials and visual aids to meet the lesson's objectives.
 - Administer performance and written tests.
 - Ensure evaluation materials and class rosters are maintained and forwarded to the appropriate administrative personnel.
 - Evaluate the training program's effectiveness.
 - Modify training materials based on evaluation of the training program.
-

Selection of Instructors

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

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

- Interview possible instructors to ensure they understand the importance of the roles and responsibilities of technical instructors and are willing to accept and fulfill their responsibilities in a professional manner.
- Maintain records of previous training, education, and work experience.

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

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Training Program Standards and Policies (continued)

Test Administration

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

DOE–HDBK–1204-97, *Guide to Good Practices for the Development of Test Items*, and DOE–HDBK–1205-97, *Guide to Good Practices for the Design, Development, and Implementation of Examinations* should be helpful.

- For the first administrations of tests, a minimum of 80% will be required for a passing score. As statistical analysis of test results are performed, a more accurate percentage for a passing score will be identified.
- Each test will be updated by the designated course administrator.

Test administration is critical in accurately assessing trainees' acquisition of knowledges being tested. These rules should be followed:

- Tests will be announced at the beginning of the training sessions.
- Instructors will 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.
- Every effort should be made to eliminate all noise during the test.
- No talking (aside from questions) will be allowed.
- Answers to question during a test will be provided, but answers to test items will not be provided or alluded to.
- Where possible, multiple versions of each test will 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.
- Each trainee will receive the results of his or her test within one week of test completion.
- Trainee scores on the tests will be kept confidential.

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Training Program Standards and Policies (continued)

Program Records and Administration

Training records and documentation shall meet the requirements of 10 CFR Paragraph 835.704 and Article 725 of the RadCon Standard.

Audits (Internal and External)

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

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

Evaluation Training Program Effectiveness

Verification of the effectiveness of radiological control training should be accomplished in accordance with DOE-HDBK-1131-98, *General Employee Radiological Training (GERT)* and DOE-HDBK-1130-98, *Radiological Worker Training*.

DOE Order 5480.20A, *Personnel Selection, Qualifications, and Training Requirements for DOE Nuclear Facilities*, made use of *DOE Standard Guidelines for Evaluation of Nuclear Facility Training Programs*, DOE-STD-1070-94, mandatory.

In addition, DOE/EH has issued guidelines for evaluating the effectiveness of radiological training through the DOE Operations Offices and DOE Field Offices.

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Course-Specific Information

Purpose

This section of the guide is to assist those individuals assigned responsibility for implementing the Plutonium Facilities Training. Standardized implementation of this training ensures consistent and appropriate training for all personnel.

Course Goal

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

Target Audience

Individuals who have assigned duties in plutonium facilities are the target audience for this course.

NOTE: 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.

Course Description

This course illustrates and reinforces the skills and knowledge needed to provide personnel with an understanding of the characteristics of plutonium and the precautions needed for working in a DOE facility.

Prerequisites

Rad Worker II

Length

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

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Course-Specific Information (continued)

Tests Sites must develop tests for this course.

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 must have related experience and be technically competent. In this course, it is imperative that the instructor have the background and experience of working in a plutonium facility. Instructors must be able to relate their own work experience to the workers in a plutonium facility. Instructors must be able to answer specific questions and use a variety of instructional material to meet the objectives.

Technical Qualifications Education:

A minimum of a B.S. degree in Health Physics or related discipline is preferred.

Certification:

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

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Course-Specific Information (continued)

**Technical Qualifications
(continued)**

Experience:

At least five years of applied radiological protection experience in an operating nuclear facility is preferred.

The areas of experience should include:

- Nuclides/isotopes of plutonium
- Properties of plutonium
- Plutonium hazards
- Radiological control policies
- Conducting surveys and monitoring for plutonium

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

**Application Package
Checklist**

The following checklist should be used before training is provided. All items in the checklist should be completed or signed off with reason for leaving the item incomplete.

- Send course announcement to point of contact.
 - Send course applications to point of contact.
 - Send course description to point of contact.
 - Send course dates to point of contact.
-

**Confirmation Package
Checklist**

The following checklist should be used before training is provided. All items in the checklist should be completed or signed off with reason for leaving the item incomplete.

- Obtain hotel reservation information.
- Send confirmation letter upon receipt of application.
- Send hotel reservation information with confirmation letter.
- Send area map with confirmation letter.
- Send classroom location, dates, and times with confirmation letter.
- List materials to be brought to class (such as badges, RadCon Standard, etc.) in the confirmation letter.

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Course-Specific Information (continued)

Confirmation Package Checklist (continued)

- ❑ Identify clothing requirements/recommendations for field exercises in the confirmation letter.
 - ❑ Provide instructor biographies with the confirmation letter.
-

Pre-Course Delivery Activities Checklist

The following checklist should be used before training is provided. All items in the checklist should be completed or signed off with reason for leaving the item incomplete.

- ❑ Send letter identifying pre-course homework.
 - ❑ Send copy of application and confirmation packages to keynote speaker.
 - ❑ Have display posters made showing room locations.
 - ❑ Have transparencies made and framed in sufficient number for each instructor.
 - ❑ Have name badges and name tents made for each participant and instructor.
 - ❑ Obtain site-specific primary responsibilities related to emergency planning.
 - ❑ Obtain site-specific records required by the RadCon Standard.
 - ❑ Obtain any site-specific lessons learned.
 - ❑ Provide site-specific information to all instructors.
 - ❑ Reserve training room(s) suitable for the activities to be completed.
 - ❑ Conduct instructor briefings (prior to and during course delivery).
 - ❑ Make travel arrangements.
-

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Course-Specific Information (continued)

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Hyde, E.K., *Synthetic Transuranium Elements*,
Washington, D.C., 1964.

Mansfield, G., *Chelatron Therapy and Wound Excision for Suspected Intakes of TRU Material*, paper presented At Lawrence Livermore National Laboratory, Livermore, CA, 1993.

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

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Instructor's Guide



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DEPARTMENT OF ENERGY	COURSE/LESSON PLAN
Course Goal: Upon completion of this training, the student will have a basic understanding of the characteristics of plutonium and understand the precautions and safeguards needed for working in a plutonium facility.	
Target Audience: Individuals who have assigned duties in plutonium facilities are the target audience for this course. NOTE: 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.	
Description: This course illustrates and reinforces the skills and knowledge needed to assist personnel with an understanding of the characteristics of plutonium and the precautions needed for working in a DOE plutonium facility.	
Prerequisites: Rad Worker II	
Length: 2 – 4 hours (depending on site-specific information)	
Objectives: Upon completion of this training, the student will be able to: <ol style="list-style-type: none">1. Describe the discovery, importance, and early production of plutonium.2. Identify the characteristics, grades, and predominant isotopes of plutonium.3. Identify the following properties of plutonium:<ul style="list-style-type: none">▪ Physical/chemical▪ Reactivity▪ Radioactivity▪ Criticality4. Identify the radiological hazards of plutonium.5. Identify the modes of entry and removal techniques for plutonium.	

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DEPARTMENT OF ENERGY	COURSE/LESSON PLAN						
<p>Objectives (continued):</p> <ul style="list-style-type: none"> 6. Identify the following control methods for plutonium: <ul style="list-style-type: none"> <input type="checkbox"/> External <input type="checkbox"/> Internal <input type="checkbox"/> Criticality 7. Identify the radiological surveys at plutonium facilities: <ul style="list-style-type: none"> <input type="checkbox"/> Detection <input type="checkbox"/> Dosimetry 8. Response to abnormal conditions 							
<p>Training Aids:</p> <table style="width: 100%; border: none;"> <tr> <td style="width: 35%; vertical-align: top;">Overhead Transparencies (OT)</td> <td style="width: 15%; vertical-align: top;">OT 1 – OT 35</td> <td style="width: 50%; vertical-align: top;">(May be supplemented or substituted with updated or site-specific information)</td> </tr> <tr> <td style="vertical-align: top;">Handouts: Lessons Learned (LL): Periodic Table:</td> <td style="vertical-align: top;">LL 1 – LL 5 (IG-1)</td> <td style="vertical-align: top;">(May substitute other lessons learned) I. History of plutonium</td> </tr> </table>		Overhead Transparencies (OT)	OT 1 – OT 35	(May be supplemented or substituted with updated or site-specific information)	Handouts: Lessons Learned (LL): Periodic Table:	LL 1 – LL 5 (IG-1)	(May substitute other lessons learned) I. History of plutonium
Overhead Transparencies (OT)	OT 1 – OT 35	(May be supplemented or substituted with updated or site-specific information)					
Handouts: Lessons Learned (LL): Periodic Table:	LL 1 – LL 5 (IG-1)	(May substitute other lessons learned) I. History of plutonium					
<p>Equipment Needs:</p> <ul style="list-style-type: none"> Overhead projector Screen Flip chart Markers Masking tape 							
<p>Student Materials:</p> <ul style="list-style-type: none"> Student Guide 							
<p>References:</p> <p>Hyde, E.K., <i>Synthetic Transuranium Elements</i>, Washington, D.C., 1964.</p> <p>Mansfield, G., <i>Chelatron Therapy and Wound Excision for Suspected Intakes Of TRU Material</i>, paper presented at Lawrence Livermore National Laboratory, Livermore, CA, 1993.</p> <p>Miner, W., <i>Plutonium</i>, U.S. AEC, Washington, D.C., 1966.</p> <p>Stein, F., <i>Instructor Competencies: The Standards</i>, International Board of Standards for Training, Batavia, IL, 1992.</p>							

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COURSE/LESSON PLAN

References (continued):

McLaughlin, T.P., Monahan, S.P., Pruvost, N.L., *A Review of Criticality Accidents*, 2000 Revision, LA-13638, May 2000.

U.S. Department of Energy, *Guide to Good Practices for Training and Qualification of Instructors*, DOE-HDBK-1001-96, 1996.

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Course Introduction

Welcome students to the course.

Introduce self and instructional team.

Define logistics.

- Safety briefing – exits/alarms
- Restrooms
- Hours – start/finish
- Breaks – frequency
- Sign-in sheet
- Test – accountability/results
- End of course evaluation

Facilitate student introduction and completion of name cards.

State course goal.

State contents of course.

Refer students to table of contents. Inform students that Appendix A contains references used to create course materials. Briefly provide overview of course.

Show OT 1, OT 2, OT 3, and OT 4.

State Objectives.

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I. History of plutonium

A. Discovery

In the earlier part of this century (1900-1940), physicists speculated that there might be elements with higher atomic numbers than uranium (at the time, the element with the highest known atomic number).

The first of these elements was found in 1940 at the University of California (Berkeley) by Edwin M. McMillan and Philip H. Abelson. The element was called neptunium after the planet Neptune. A few months later, Arthur C. Wahl, Glenn T. Seaborg, and Joseph W. Kennedy produced plutonium by bombarding uranium-238 (U-238) with deuterons in an accelerator called a cyclotron (also called an "atom smasher"). The cyclotron is a large machine that uses electromagnets to accelerate charged atomic particles (protons and beta particles) to extremely high speeds and then smash them into a target material.

B. Early research

On March 28, 1941, scientists at the University of California (Berkeley) demonstrated that plutonium-239 (Pu-239) could undergo fission with thermal/slow neutrons. Fission is the process of splitting atoms through which large amounts of energy (200 Mev per fission as compared to 4 ev released during combustion of an atom of carbon) are released, as well as excess neutrons (between two and three), which can then split other atoms to keep a chain reaction going.

Obj. 1

Describe the discovery, importance, and early production of plutonium.

Show OT 5.

Show OT 6.

Explain the basic process of nuclear fission.

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It was soon realized that this "atomic energy" could possibly be used as a weapon. Because of the possibility of using atomic energy for military purposes, the discovery of plutonium was not announced publicly. Further work with plutonium was done in strict secrecy. Although very small quantities of plutonium could be produced in a cyclotron, this method was not capable of producing the large quantities desired for military use.

This problem was solved on December 2, 1942, at the University of Chicago, when a self-sustaining nuclear chain reaction was achieved. By using U-238 atoms to absorb the excess neutrons, plutonium could be produced.

C. Reactor plutonium

Within a few months, two plutonium-producing reactors were built: one in Oak Ridge, Tennessee, and one near Richland, Washington. The actual weapons were built at Los Alamos, New Mexico, which was known as Project Y.

The first atomic bomb (made with plutonium) was detonated in the desert 60 miles northeast of Alamogordo, New Mexico, on July 16, 1945. The atomic age had begun.

More plutonium production reactors were later built at the Savannah River Plant near Aiken, South Carolina, and at the Hanford Engineering Works near Richland, Washington. These sites became the principal sources of plutonium for weapons production in the United States.

Show OT 7.

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D. Natural plutonium

The half-life of plutonium is so short compared to the age of the earth that if plutonium had existed when the earth was formed, plutonium would not exist today. So, for all practical purposes, plutonium must be man-made.

Remnants of a natural reactor have been discovered in Africa, and it is believed to have operated for millions of years. Very small traces of plutonium have been found in uranium ore, resulting from cosmic-ray produced neutron bombardment of uranium.

II. Nuclides/isotopes and uses of plutonium

A. Predominant plutonium isotopes

Atoms of a specific element can exist in several forms. The difference between the forms is the number of neutrons in the nucleus. These forms are called isotopes of an element. Most elements in nature have several different isotopes. (They have the same number of protons, but a different number of neutrons). Plutonium has 15 isotopes.

Nuclide is a broader term than isotope and refers to any combination of protons and neutrons that exists in more than a transient state. An isotope is a specific combination of protons and neutrons, which defines it as a subset of an element; the two need to be referenced together, such as "an isotope of plutonium."

The predominant nuclides are Pu-238, Pu-239, Pu-240, Pu-241, and Pu-242. Each has a specific application.

Explain that the half-life is the amount of time it takes for one-half of the material to decay.

The earth is thought to be approximately 4.5 billion years old.

Show OT 8.

Obj. 2
Identify the characteristics, grades, and predominant isotopes of plutonium.

Explain that an isotope is an element with the same number of protons, but a different number of neutrons.

The shorter-term nuclide will be used for this instruction.

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B. Pu-238 – heat-source grade

Heat-source plutonium has the highest Pu-238 content and can be produced by exposing U-235 to neutron bombardment until U-237 is formed. U-237 has a short half-life (6.75 days) and decays to long-lived (2 million years) neptunium-237 (Np-237). Neutron activation of Np-237 produces Np-238, which then decays to Pu-238.

In order for a nuclide to be used for thermal (heat) energy, it must have a half-life greater than 100 days, but less than 100 years. If the half-life is less than 100 days, the nuclide will have to be replenished often. If the half-life is greater than 100 years, the decay rate (activity) will not be high enough to create enough heat to be considered a good heat source.

The half-life of Pu-238 is short enough (88 years) to create a high heat output and long enough to provide long-term power without replenishment. These characteristics make it an ideal heat source for thermoelectric generators. These generators have been used to power ocean buoys and space satellites where long-term, reliable power is essential.

C. Pu-239 – weapons grade

Neutrons absorbed by U-238 atoms cause the formation of U-239, which then decays and eventually forms Pu-239. Pu-239 can fission.

Weapons grade plutonium has the highest content of Pu-239 and is mainly used in nuclear warheads.

D. Pu-240, 241, 242 – reactor grade

In general, the longer Pu-239 remains exposed to neutron bombardment in a reactor, the more Pu-240, Pu-241, and Pu-242 will be produced.

Show OT 9.

Define neutron activation

Show OT 10.

Pu-239 half-life: 24,000 years

Show OT 11.

Pu-240 half-life: 560 years

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The actual nuclide and quantity produced depend on the source material, type of reactor, and length of irradiation time.

The reactor grade, with its higher Pu-240 content, presents a much higher gamma and neutron dose rate than does the weapons grade. The reason is that the Pu-240 has more than 1000 times the spontaneous fission rate than does the Pu-239. Pu-241 and Pu-242 also have a much higher spontaneous fission rate. The prompt gammas and neutrons from the spontaneous fission and the fission product gammas produce a much higher overall dose rate for the reactor grade material.

Table 1 shows the approximate weight percentages of the three grades of plutonium.

In November 1946, the first nuclear reactor to use separated out plutonium as fuel, called Clementine, was activated at Los Alamos. Since more plutonium can be bred during the operation of the reactor, the country's nuclear fuel reserves could be greatly increased as a result.

Refer students to Table 1.

Table 1

Approximate Weight Percentages of Predominant Nuclides			
Nuclide	Heat-Source	Weapons Grade	Reactor Grade
Pu-238	90.0	<0.05	1.5
Pu-239	9.1	93.6	58.1
Pu-240	0.6	6.0	24.1
Pu-241	0.03	0.4	11.4
Pu-242	<0.01	<0.05	4.9

E. Other uses of plutonium

Plutonium can also be used in neutron detectors and neutron sources, as well as in the production of other man-made elements.

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III. Properties of Plutonium

A. Physical and chemical

Reactor-produced plutonium goes through several different chemical processes before it becomes a solid metal. Irradiated nuclear fuel elements are dissolved in strong acid and the plutonium is chemically extracted from the solution. Plutonium solutions do not readily create airborne contamination problems, but contamination containment is difficult because of the corrosive nature of the solutions.

The solution is put through another processing stage that converts it from a liquid to a powder. Airborne contamination problems are more likely to occur in this powdered form. Because it is in a more dispersible form, this is done inside gloveboxes.

The powder is then placed in a crucible mold and heated without melting until it becomes a solid metal. The metal has a bright, silver-like appearance at first, but it oxidizes very quickly to a dull gray. It is about as hard and brittle as gray cast iron unless it is alloyed with other metals to make it soft and ductile. Although it is a metal, it is not a good conductor of heat or electricity like most other metals.

There are two difficult conditions that need to be dealt with in the processing:

- It takes tons of irradiated uranium in order to extract grams of plutonium.
- Intense radiation is present in the production, processing, storage, and waste handling. To protect workers, these processes are performed within shielded cubicles or some other shielded containment.

Obj. 3

Identify the following properties of plutonium:

- Physical/chemical
- Reactivity
- Radioactivity
- Criticality

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Table 2 contains a brief summary of some of the features of this metal.

Show OT 12 and OT 13.

Refer students to Table 2.

Table 2

Physical and Chemical Properties of Plutonium	
Density	15.9-19.9 g/cm ³ , depending on metal phase. Loose PuO ₂ powder has a density of about 2 g/cm ³ , and sintered pellets have a density of 10.3-11.0 g/cm ³ .
Melting point (pure metal)	640° C
Alloys	Up to 2000° C; varies with alloy.
Boiling point (pure metal)	3327° C
Oxidation rate	Slow in dry air. Rapid under moist conditions or when heated. May result in a low spontaneous ignition temperature.
Action of acids and bases	Dissolves readily in concentrated hydrochloric, hydriodic, and perchloric acids. Attacked by most dilute acids; not readily attacked by concentrated sulfuric and nitric acids or sodium hydroxide solutions.

B. Reactivity

Plutonium metal has proven to be quite pyrophoric under certain conditions. It reacts with oxygen very slowly in dry air, but rapidly in moist conditions, or when the metal is heated.

A pyrophoric reaction can happen with larger pieces of plutonium; however, fire is more likely to occur when the plutonium is in a more dispersed form, such as chips, powder, or turnings. For this reason, it is handled in a moisture-free (dry air) or oxygen-free (inert) atmosphere. Note: With an atmosphere that contains only 5% oxygen, the metal will burn easily. However, when the oxygen content is reduced to 1%, a fire will not continue to burn unless heat is supplied.

Powder is **most** reactive.

Explain spontaneous combustion.

Inert: Nonreactive; for example, helium, argon.

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Gloveboxes with dry air or inert atmospheres are still not suitable for long-term storage. Long-term storage of Pu-239 is accomplished by placing the metal in a sealed can, which is usually placed inside one or more cans. As the plutonium decays, the can may build up pressure due to accumulation of helium from the alpha particles and from radiolysis of impurities. The cans are monitored for "bulging" so they can be repacked before the pressure builds up and the cans burst. Long-term storage of plutonium will be in cans developed by DOE for the complex. These are called 3013 cans and are being used by five sites at present.

Pu-238 can generate enough heat to require handling with insulated gloves (or another insulator) and packaging in special containers that dissipate heat. If Pu-238 is stored next to flammable material, a fire may result. If it is stored near material that degrades by heat, flammable or explosive gases may be formed.

There can be other factors that involve fires, such as different alloys that burn or impurities that may be pyrophoric. Highly pure plutonium metal will burn without producing a flame.

C. Radioactivity

All 15 nuclides of plutonium are radioactive and have an atomic number of 94. This means plutonium has 94 protons and is a transuranic element, one of the heaviest elements known. Any element with a higher atomic number than uranium (atomic number 92) is called a transuranic element. Physicists continue to produce these elements, and at present the Eighth Edition of the Table of Isotopes lists elements through 111. In August 1999 physicists reported production of a new element 118 (and its daughter 116) by colliding intermediate mass ions. Transuranic elements are usually referred to as "TRU" elements.

Optional:
Show Pu as an element in the periodic table and explain what the symbol and numbers mean.

Show OT 14.

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Plutonium emits one or more of the following types of radiation: alpha, beta, neutron, gamma, and x-ray. The half-lives of nuclides range from 21 minutes for Pu-233 to 80 million years for Pu-244.

Alpha radiation and low-energy (less than 70 keV) beta radiation will not penetrate the dead layer of skin and present no external hazard. These become hazardous when they are introduced inside the body, where they have direct contact with living cells.

With plutonium, neutron radiation is the most penetrating and can be a significant biological hazard.

Most x-ray and/or gamma radiation from plutonium is of lower energy, ranging from 17-20 keV, and is moderately penetrating. This radiation becomes a concern mostly with those handling the material.

There is an additional radiological problem with Pu-241. It is impossible to separate plutonium nuclides to 100% purity; there is always some Pu-241 present. The Pu-241 decays to americium 241 (Am-241). Am-241 emits a higher-energy gamma ray, which is a concern. This americium "in growth" results in increasing radiation levels for many years. This can contribute to significant doses, since some applications may have 30%-50% Pu-241.

D. Criticality

While several plutonium nuclides can fission, only Pu-239 is of practical importance as a criticality concern. A criticality accident involves an uncontrolled chain reaction that releases large quantities of heat, neutrons, and gamma radiation. It does not create an atomic explosion. Facilities that possess fissile material have criticality detection systems to warn workers of an event. Remember, if a criticality accident does occur, exit as quickly and safely as possible. **JUST GET OUT!**

Discuss the criticality accident at the Fuel Fabrication Plant in Tokai-mura, Japan, September 1999.

Refer students to LL 5.

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IV. External and Internal Hazards

A. External exposure hazards

1. Alpha radiation

Alpha radiation is not an external dose concern because it will not penetrate the dead layer of skin. Alpha radiation is primarily a concern if it is introduced inside the body.

2. Gamma and x-ray radiation

All plutonium nuclides emit large quantities of low-energy x-rays, and the "in growth" of Am-241 emits higher-energy gamma rays. These contribute to external exposure and especially extremity exposure.

3. Neutron radiation

- Several plutonium nuclides emit neutron radiation through spontaneous fission (notably from Pu-238, Pu-240, and Pu-242). The rate at which these neutrons are emitted is different with different nuclides of the plutonium.
- Neutron radiation is also produced by an alpha-neutron reaction. When alpha particles interact with the nucleus of an atom of a lighter element (such as beryllium or lithium), the nucleus is left in an excited state. To return to the ground state, the atom emits a neutron with an energy of about 2.5 MeV.
- An alpha particle emitted by a plutonium atom may penetrate the nucleus of a fluorine atom in the compound PuF₄. The excited nucleus decays by emitting a neutron. The neutron yield and energy of the alpha-neutron reaction are dependent on the alpha energy and the material.

Obj. 4
Identify the radiological hazards of plutonium.

Show OT 15.

17-20 keV
60 keV

Show OT 16.

Define an alpha-neutron reaction

Show OT 17.

PuO₂ is the most common chemical compound of Pu. PuF₄ is an intermediate compound in the fuel cycle.

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4. Criticality

- A criticality event can produce a life-threatening dose of radiation to those who are in the immediate vicinity.
- Example: A burst of 10^{18} fissions in a metal system may produce doses of 600 rad up to a distance of 30 feet and 100 rad up to around 70 feet (assuming there is no shielding). Also, there may be enough heat generated to melt the system containing the plutonium. The fission products produced will create residual contamination and lasting radiation problems.

Show OT 18.

Discuss LD_{50/30}:
Lethal dose at which 50% of an irradiated population dies within 30 days.

For humans, this dose is 450 rem, whole body.

B. Internal exposure hazards

Plutonium is a heavy metal that is chemically toxic as well as radioactive. Many other heavy metals such as arsenic, lead, and uranium are also chemically toxic.

Plutonium is primarily an alpha emitter and is particularly hazardous if taken into the body. Alpha particles do not travel far in material, which means they lose all of their energy in a short distance. Alpha particles cannot penetrate the dead layer of skin on the body. However, when they are in direct contact with our living cells, such as in our lungs, they are a hazard. Other alpha emitters include natural radon, which is also an inhalation concern.

Alpha particles are thought to be approximately 20 times more damaging to tissue than beta particles.

Show OT 19.

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V. Modes of Exposure and Treatment

A. Modes of exposure

Plutonium may enter the body by the following modes:

1. Inhalation (breathing)

For plutonium (and many other radionuclides, as well), inhalation is the most common route of intake into the body. To determine the level of airborne radioactivity that workers are exposed to occupationally, air samples are routinely collected and analyzed at DOE plutonium facilities. The resulting concentration (in units of activity per volume) is compared to a guideline value known as the derived air concentration (DAC). If a worker were to breathe one Pu-238 DAC ($2E-12$ uCi/ml for class W) for one working year (2000 hours), at the end of the year, the committed dose equivalent (summed over 50 years) would be 50 rem to the critical organ (bone surfaces). This would equate to a committed effective dose equivalent of 1.5 rem, if the smaller doses to the other organs are neglected.

An occupied area containing airborne concentrations of radioactivity that exceed or are likely to exceed the DAC values provided in Appendices A and C of 10 CFR 835 or if an individual could receive an intake exceeding 12 DAC-hours in a week must be posted as an "Airborne Radioactivity Area" according to 10 CFR 835 and the RadCon Standard. Posting the area would, in turn, necessitate a consideration of respiratory protection.

Obj. 5
Identify the modes of entry and removal techniques for plutonium.

Show OT 20.

Define DAC.

$50 \times 0.03 = 1.5$

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2. Injection (through wounds)

Although inhalation is the most common mode of intake, injection through wounds can be very hazardous. In these cases, large amounts of radioactive or toxic material could be deposited directly into the body and then absorbed into the bloodstream.

3. Ingestion (eating or drinking)

Ingestion through eating or drinking is very rare and usually only happens when there is contamination around the nose or mouth. Depending on the chemical composition, up to 99.9% of the plutonium can pass through the body and be eliminated.

4. Absorption (skin contact)

Absorption is extremely rare and is not a real concern except when using plutonium hexafluoride or acidic solutions that may contact and burn the skin.

B. Intakes

Although operations are planned and precautions are taken to avoid any significant intake of radioactive materials, the possibility of an intake always exists. When plutonium gets into the body, it will be distributed to various organs, depending on its physical and chemical makeup.

Particles that are inhaled and deposited in the lungs may stay there for years. During this time, they could be slowly absorbed into the bloodstream (as is the case with insoluble plutonium oxide). Soluble plutonium is absorbed into the bloodstream much more rapidly.

Show OT 21.

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Once in the bloodstream (whether inhaled or injected), plutonium will distribute to certain target organs, such as bone surfaces, the liver, and, to a lesser extent, the gonads. After plutonium reaches these organs, it is eliminated extremely slowly through the feces and urine. The biological half-life of plutonium is 170-180 years. Biological half-life is the time required for the body to eliminate one-half of the uptake.

Because plutonium may remain in the body for a long time and the alpha energy is fairly high, target organs can receive large (greater than 50 rem) doses over time.

4-6 MeV

C. Medical treatment

1. Chelation therapy

Chelation therapy is recommended for plutonium inhalation. It is also recommended for injections through wounds, and excision may also be necessary.

Show OT 22.

Chelating agents are drugs that increase the solubility of plutonium and enhance the body's ability to eliminate it through the urine.

Refer students to
handout
LL 3.
Discuss (optional)

DTPA (diethylenetriaminepentaacetic acid) is generally more effective than other chelating agents. It is not a new drug and has been used on hundreds of individuals. However, because there is no commercial use for DTPA, it is categorized as an Investigational New Drug (IND). Because it is an IND, a consent form must be signed prior to administering it.

There are two primary types of DTPA: calcium-DTPA (Ca-DTPA) and zinc-DTPA (Zn-DTPA). Ca-DTPA is more effective than Zn-DTPA in the first 24 hours. Because it depletes more of the heavy metals in the body (such as iron or zinc), it is not recommended for long-term treatment.

Show OT 23.

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To avoid long-term depletion, Ca-DTPA is administered initially, then followed with Zn-DTPA. Ca-DTPA should never be used in the treatment of pregnant women since it could cause birth defects.

Substantial dose reductions can be achieved if DTPA is administered within a few hours (recommended within one hour) of the intake. Dose reductions from 10% to 90% have been achieved for wound or burn cases and up to 30% for inhalation cases

2. Excision

Because it is difficult to detect contamination in an injection/wound, a radiation measurement instrument called a wound counter is used. If the wound counter reveals contamination, excision is sometimes recommended. Excision is the surgical removal of contaminated tissue.

If a large amount of contamination is located at the wound site, excision can dramatically reduce the exposure. Dose reductions of up to a factor of 100 have been achieved with excision.

Usually, only a small amount of tissue is removed. This does not present a significant health hazard.

VI. Radiological Controls

A. Hierarchy of controls

The preferred hierarchy of controls is listed below:

- Engineered
- Administrative
- Personnel protective clothing/equipment

Insert site-specific policy here.

Refer students to handout LL 3.
Discuss (optional).

Wound counters will be explained in more detail later in the lesson.

Insert site-specific policy here.

Obj. 6
Identify the following hazard control methods for plutonium:

- External
- Internal
- Criticality

Show OT 24.

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<ol style="list-style-type: none">1. Engineered controls are built into the system. Engineered controls include shielding, ventilation, and containment systems.2. Administrative controls for plutonium facilities are the same as any other radiation source.3. Personnel protective clothing/equipment	<p>Instructors: Insert facility-specific information.</p>
<p>B. External hazard controls</p> <ol style="list-style-type: none">1. Time – plan ahead to avoid spending any more time near radiation sources than necessary.2. Distance – the further from the radiation source, the lower the dose. Example: With a point source, if the distance to the source is decreased by one-half, the dose will increase by four times.3. Shielding – plutonium emits low-energy x-ray and gamma radiation that is easily shielded with small amounts of steel or lead. Also, the use of lead-lined glovebox gloves helps reduce extremity dose for those who handle plutonium.	<p>Show OT 25.</p> <p>Many facilities have identified low dose areas. These areas should be utilized when practical.</p> <p>The first few inches are dramatic with small or point sources and become less dramatic with larger or plane sources.</p>
<p>In a plutonium facility, shielding for neutrons must be addressed as well as shielding for x-ray and gamma radiation. Neutrons are more penetrating and they are harder to shield. The most effective shielding employs materials that have hydrogen, such as water, oil, polyethylene, or paraffin. Many gloveboxes will have hollow walls and windows filled with one of these substances. But caution must be exercised in the use of these highly flammable hydrocarbon products.</p>	

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4. Source reduction – the source of the radiation can be reduced by decontamination, better storage methods, or elimination of the source altogether. Extremity dose can be reduced by periodically sweeping/wiping the plutonium dust from the inside of the gloveboxes and gloves.

Protective clothing, commonly of Tyvex material, is used to keep contamination off personal clothing and skin. It does not stop the external radiation exposure (except alpha rays), but it helps prevent the spread of contamination both onto and into the body.

C. Internal hazard controls

During operations in which there is a potential to breach a containment system (such as glove changes or seal-outs) and create airborne radioactivity, respiratory protection is the primary method of preventing internal dose from inhalation. To minimize the possibility of inhalation, individuals must ensure the physical integrity of the respirator, obtain a good seal, and ensure the protection factor of the respirator is adequate.

There are also methods to prevent injection wounds (such as placing leather gloves over glovebox gloves or ensuring there are no sharp objects inside containments). If personnel have any suspicion of an injection wound, they should immediately seek the assistance of the site radiological control organization.

Remember:
Contamination emits radiation.

Refer students to
handout LL 1.
Discuss (optional).

Refer students to
handout LL 4.
Discuss (optional).

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1. Containment

Because plutonium is of particular concern if inhaled, special precautions are taken to avoid airborne contamination. There are many different types of containments that, when used in conjunction with ventilation, help prevent the loss of material and thus minimize dose to the workers.

Gloveboxes are almost always used when handling plutonium in a dispersible form. However, properly vented hoods are acceptable for handling the very small quantities used in a research laboratory. Proper hood design is critical for plutonium and only very small quantities should be used.

Gloveboxes, tanks, and piping are examples of "primary containments," because there are no system openings. Gloveboxes have ports with long plastic sleeves attached that allow material to be "sealed in" or "sealed out" from the glovebox without breaching the containment.

Types of equipment such as fumehoods are "primary confinements," since they are the barrier closest to the source. Primary barriers require good ventilation to maintain contamination control. **Do not insert your hands into a primary barrier unless you have been trained and authorized to do so.**

Show OT 26.
Never climb on gloveboxes or equipment.

Show OT 27.

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The room that encloses the primary system and is intended to provide containment if the primary fails is called secondary containment. The building that encloses the systems is the final barrier.

2. Ventilation

Maintaining proper airflow is essential for the safe operation of a plutonium facility. Air flows from regions of high pressure to regions of low pressure. Ventilation systems are engineered so that air flows from areas of low contamination to areas of greater contamination. Air balance is maintained by using damper controls, air locks, and backup safety systems. Air balance is also maintained by controlling the position of the inside doors. **Ventilation control doors should not be blocked open, or ventilation balance could be lost. Also, do not operate any equipment unless you have been trained and authorized to do so.**

Devices such as tents or glovebags are used to provide local containment for maintenance activities. These containments normally have local ventilation and exhaust filtration. A bagless transfer system for moving items out of gloveboxes has been developed for use throughout the complex.

May need to use site-specific terminology.

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The best way to maintain contamination control after a loss of containment is to decontaminate to low or non-detectable levels. However, in some instances, contamination must be fixed in place. This is usually done by painting the surfaces of gloveboxes, walls, floors, etc. Because there is a potential for contamination control problems if these surfaces are disturbed, individuals should not scrape surfaces or remove tape unless precautions are taken.

Show OT 28.

D. Criticality controls

Many facility-specific engineered and administrative controls have been put in place in an effort to prevent an uncontrolled criticality. This course does not provide adequate training in the handling of fissile material. Examples of engineered controls are specific piping, container shape, and poisons (neutron-absorbing material). Examples of administrative controls are procedures on container spacing and the amount of material in the container.

Refer students to Handout LL 5.

Define fissile

Show OT 29.

Only workers who are properly trained should handle fissile material. If you are not trained as a fissile material handler, **do not**, under any circumstances, handle fissile material.

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Because liquid containing plutonium is a special criticality concern, care must be taken when handling plutonium-bearing liquids. Containers that could hold liquid must not be placed in or under gloveboxes or hoods unless they are criticality safety approved.

E. Administrative controls

There are many administrative controls to reduce doses. The following are just a few that should apply to all sites:

- Posting
- Training
- Housekeeping
- Maintaining access control
- Using Radiation Work Permits
- Stopping work

Show OT 30.

Ask students to name other ways to reduce dose. Write responses on flip chart. Encourage students to write other items in the Student's Guide.

Responses may include the following:

- Posting
- Shielding
- Training
- Pre-job planning
- Minimizing materials
- Surveys
- Remote operations
- Housekeeping
- Containments
- Protective equipment
- Fire prevention
- Storage control
- Inventory control
- Vacuums (high-efficiency particulate air)
- Ventilation

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VII. Radiological Surveys and Monitoring at Plutonium Facilities

A. Surveys

1. Radiological control surveys

In order to maintain good radiological controls, the radiological control organization establishes a program to periodically survey most areas in the buildings. Rooms are not the only things surveyed. Equipment (such as gloveboxes and gloves, hoods, and piping) is also included. A good radiological control program aids in early detection of contamination.

2. Radiological control practices

Personnel who work with or around plutonium should perform periodic surveys. For instance, when working in gloveboxes, personnel should check periodically (every 15-30 minutes) to ensure that there has been no compromise of the port gloves by monitoring their hands and arms on radiation detection instruments. If contamination is found, they should survey any area of the body that may have been contaminated (such as the hands, arms, chest, or face).

Show OT 31.

Obj. 7
Identify the radiological surveys at plutonium facilities.

Refer students to Handout LL 2.
Discuss (optional).

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3. Portable radiation survey instruments

- Alpha

Because alpha particles travel only a short distance in air (typically less than 1 inch), surveying for alpha radiation is more difficult than for beta or gamma radiation. Proper survey techniques require that the probe be held close to the surface (approximately one-fourth of an inch). The survey speed has to be slow (1-2 inches per second).

Alpha radiation can be shielded with a thin film of water or dirt; therefore, care must be taken when performing surveys. Because of possible water shielding, personnel must not be perspiring and material must be dry.

- Beta

One type of portable survey meter is designed to measure both beta and gamma radiations. A sliding shield is used to differentiate between them (closed for gamma measurements). Like alpha counting, the distance at which measurements is made is important.

- Gamma

Because of the low energy of the gamma radiation, not all dose rate instruments can be used. Due to the low energy, radiation levels may drop off rapidly in a short distance, causing these instruments to have readings lower than the actual surface dose rate.

Friskers is an example.

The measurement of neutrons requires specific instruments designed for that task.

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- Neutron

Be aware that it is possible to have a neutron dose rate when there is little or no gamma dose rate. Therefore, special surveys for neutrons may need to be done in areas where gamma radiation fields would be expected.

Add facility-specific information.

4. Personnel contamination monitors

Personnel survey instruments are usually placed at the exits from radiologically controlled areas. Personnel frisking shall be performed after removal of protective clothing and prior to washing and showering. The use of a personnel contamination monitor (such as a portal monitor or hand and foot counter), if available, is encouraged by the RadCon Standard. Personal items such as notebooks, papers, flashlights, shall be subjected to the same frisking.

5. Airborne radioactivity

- Continuous air monitors (CAMs)

It is important to alert workers when airborne radioactivity levels rise because inhalation is the most common pathway into the body.

Identify site-specific terminology for CAM alarms/set points.

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CAMs collect radioactive material from the air over an extended period of time and measure the activity. If a CAM activates in the room you are in, LEAVE as quickly and as safely as possible. Get at least one air space away (next room or farther) from the alarm and notify the site radiological control organization immediately.

Identify site-specific emergency exiting instructions.

- Fixed air samplers

Facilities are required to sample the air in areas where an individual is likely to receive an exposure of 40 or more DAC-hours in a year. Real-time air monitoring shall be performed to detect and provide warning of airborne radioactivity concentrations that warrant immediate action to terminate inhalation of airborne radioactive material. Fixed air samplers are used in these areas (they may also be in areas with CAMs). They are sensitive to low levels of airborne radioactivity (they are capable of determining a fraction of a DAC), but do not have alarm capabilities to alert workers to airborne radioactivity.

- Breathing zone

Airborne radioactivity is easily influenced by air currents, and air samplers (fixed or CAMs) should be strategically placed to represent the workers' "breathing zone." The breathing zone is the air space where the workers will be breathing the air. If the air samplers are not located in the breathing zone, a worker could receive internal contamination with no indication from the air monitoring systems.

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- Lapel air samplers

Lapel air samplers are small battery-powered devices, attached to workers' lapels, that draw air through a filter to collect radioactive particulates for determination of the air concentration breathed by the worker.

B. Personnel monitoring

1. External dosimetry

The most common device used to monitor worker dose is the thermoluminescent dosimeter (TLD). Dosimeters can be configured to monitor beta, gamma, x-ray, and neutron radiation.

Supplemental dosimeters (TLDs in finger rings or wrist bands) may also be worn for monitoring extremity dose.

There are dosimeters and gamma pencils equipped with alarms that can be used, but they must be specially made for low-energy gamma rays. Nuclear accident dosimeters (NADs) are required for facilities with sufficient quantities of plutonium to form a critical mass. They are issued to personnel and are also stationed throughout the facility. They contain different types of materials that become radioactive through neutron activation. The neutron dose is determined by evaluating the amount of activation of the NAD material.

Show OT 32.

Obj. 7

Identify the following monitoring techniques for plutonium:

- Detection
- Dosimetry

Insert site policy for wearing dosimeters.

Insert site policy for use of finger rings.

Use site-specific terminology for NADs.

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2. Internal dosimetry

Indication of internal exposure is achieved through many different methods. For instance, nasal smears are used to indicate exposure to airborne radioactivity. The presence of contamination in the nose is a good indicator that the worker inhaled radioactive material. However, it is common knowledge that the absence of contamination in the nose does not prove an intake did not occur. If there is a positive indication, other methods are used to measure how much plutonium has been taken into the body.

- Direct measurements

Plutonium's low-energy x-rays and gamma radiation (17-20 keV) are not readily detected. However, the decay product, Am-241, emits gamma radiation (60 keV) that can be detected with specially designed detectors. Lung counters are special detectors that are placed over the lungs to determine the amount of radioactive material in the lungs.

Wound counters are devices that can estimate the amount of plutonium in injections/wounds. They are small detectors that are placed directly over the wound.

Insert site-specific policy on bioassay, frequency, and measurement capabilities.

Show OT 33.

17-20 keV
60 keV

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- Indirect measurements

Bioassays are used to determine internal uptakes of plutonium. Urine and/or fecal samples are collected, reduced chemically, and counted for the plutonium content. Baseline bioassays are performed prior to beginning a new job to find out if the worker already has incorporated radionuclides. Termination bioassays are performed to document if any radionuclides have been incorporated during the work assignment that is completed.

Routine bioassays are performed to verify the effectiveness of workplace controls and to identify workers who may have had an intake, whereas non-routine bioassays are done after a suspected intake of plutonium is identified. Baseline bioassays are performed before a worker begins a new job to find out if he has a deposition of plutonium. Termination bioassays are performed when a worker stops work or leaves his job to find out if he has a deposition of plutonium and if so, to calculate his dose.

Soluble plutonium retained in the body is excreted mainly through the urine. Following an incident, fecal sampling is done. These samples are more sensitive as to intake, but less of a quantitative indicator of plutonium uptake.

VIII. Response to abnormal conditions

A. Unexpected adverse situations

To properly deal with unexpected adverse situations in a plutonium facility, a well-developed program and trained personnel should be in place.

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B. Abnormal conditions could include the following: Show OT 34.

- Fires/explosions
- Natural disasters
- Plutonium releases
- Failure of systems (e.g., ventilation)
- Other hazards

C. Fire safety

Show OT 35.

Because of the inhalation hazard, fires in plutonium facilities require particular care.

It is important to distinguish between fires that threaten to involve plutonium and those in which the plutonium is burning. For plutonium metal, complete exclusion of oxygen and/or rapid heat removal are the only truly effective means to extinguish fires. Due to reactivity and criticality concerns, water may not be the appropriate extinguishing agent for a fire, as it acts as a moderator and may lead to criticality. Fire systems are therefore tailored to the facility situation.

Good housekeeping is more than keeping things picked up and in their assigned place to reduce tripping hazards and present a pleasant work environment and a better appearance to inspectors. Consideration must also be given to combustible loading and the storage and use of combustible and flammable materials. The quantity of chemicals and all materials should be minimized, as these contribute to fire initiation, reactions, fire intensity, waste production, and spread of contamination.

Insert facility-specific fire information.

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D. Facility alarms

Insert facility-specific alarms and emergency response information.

Summarize lesson.

Review objectives.

Remind the participants that most of them will be allowed unescorted access to plutonium radiological control areas. As such, there will probably not be someone present who will prevent them from taking some “minor” acts that could lead to very undesirable consequences. Some of these actions have been explicitly mentioned in the course, and others can be inferred. Ask the students to relate what they have learned, and what they might infer from the course materials.

Students may relate the following:

Do not disturb equipment unless authorized to do so.

Do NOT:

- Turn off CAMs
- Reposition valves
- Reset breakers and switches

Do not disturb gloveboxes.

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Do NOT:

- Climb on gloveboxes
- Insert arms into gloves or open-faced hoods
- Place containers under gloveboxes, especially to catch liquids
- Disturb surfaces on the walls, floors, or equipment
- Block vents or air controls to gloveboxes or hoods

Do not disturb the ventilation.

Do NOT:

- Prop doors open, either outside doors or inside doors
- Change ventilation and temperature controls

Do not disturb surfaces of rooms or equipment.

Do NOT:

- Chip paint
- Drill holes
- Breach lines

Know the facility emergency procedures.

Ask for questions.

Hand out test.

Have students complete evaluation form.

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Overhead Transparencies



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Objectives

- Describe the discovery, importance, and early production of plutonium.
- Identify the characteristics, grades, and predominant isotopes of plutonium.

Objectives (cont.)

- **Identify the following properties of plutonium:**
 - **Physical/chemical**
 - **Reactivity**
 - **Radioactivity**
 - **Criticality**

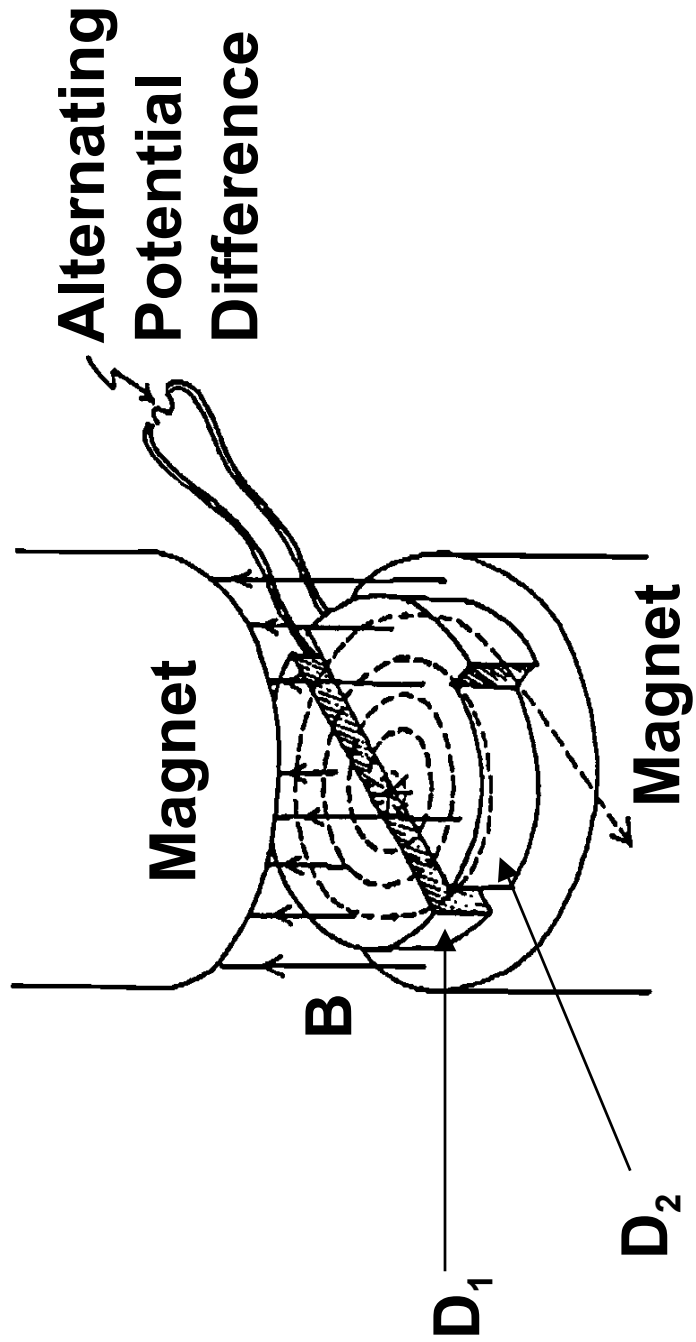
Objectives (cont.)

- **Identify the radiological hazards of plutonium.**
- **Identify the modes of entry and removal techniques for plutonium.**
- **Identify the control methods for the following plutonium hazards:**
 - **External**
 - **Internal**
 - **Criticality**

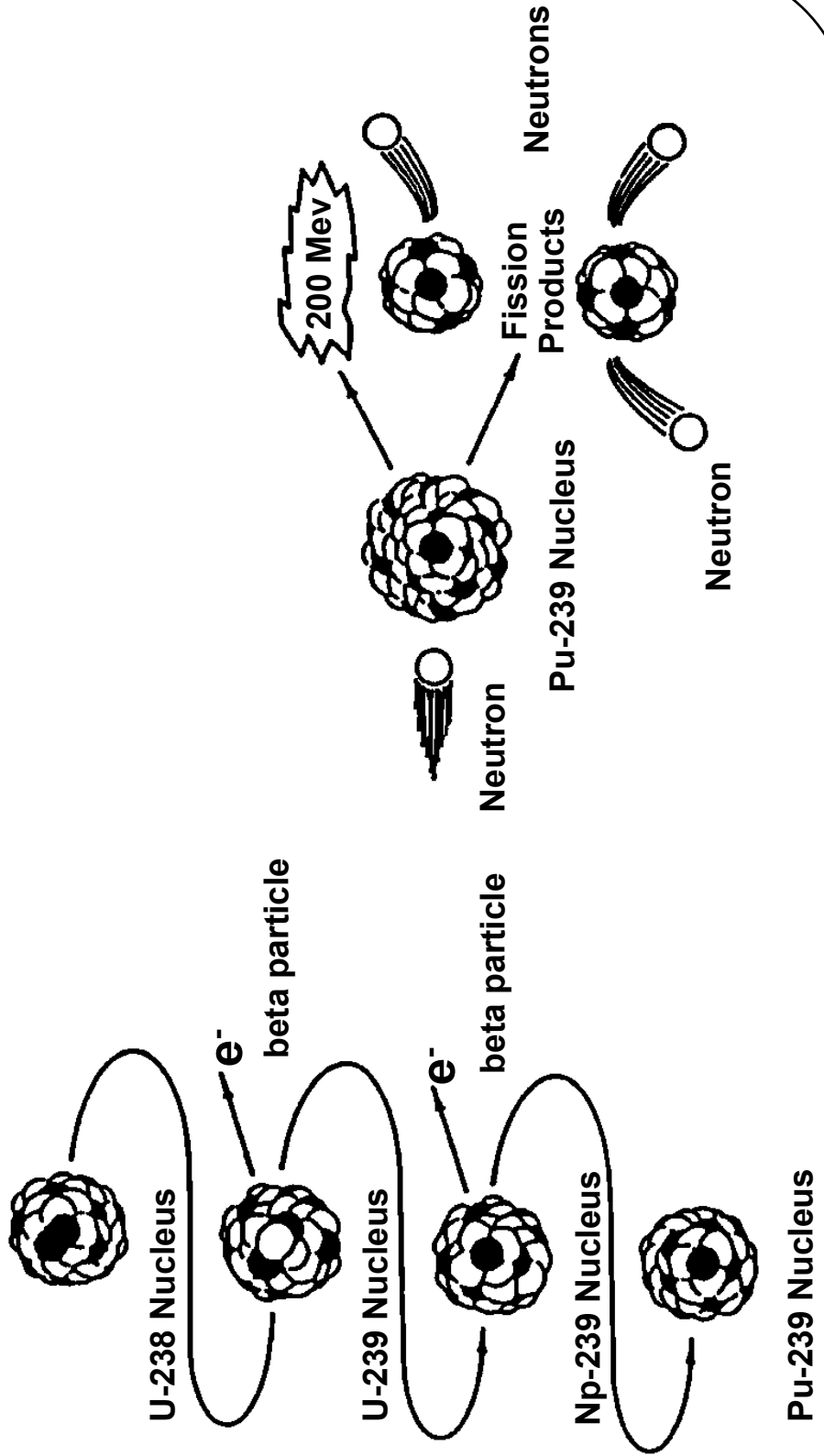
Objectives (cont.)

- Describe the following monitoring techniques for plutonium:
 - Detection
 - Dosimetry

The Cyclotron

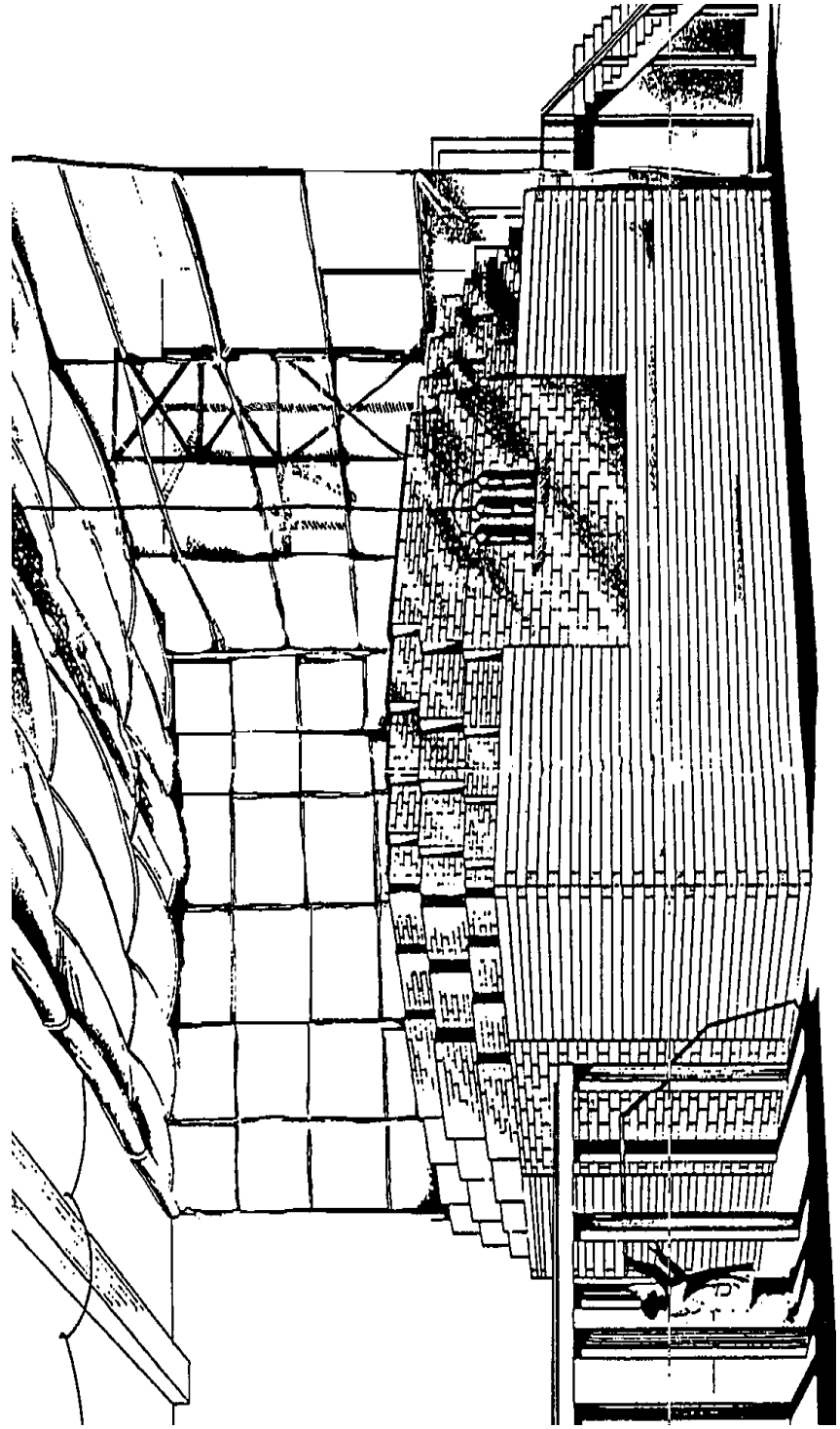


Pu-239 Production and Pu-239 Fission



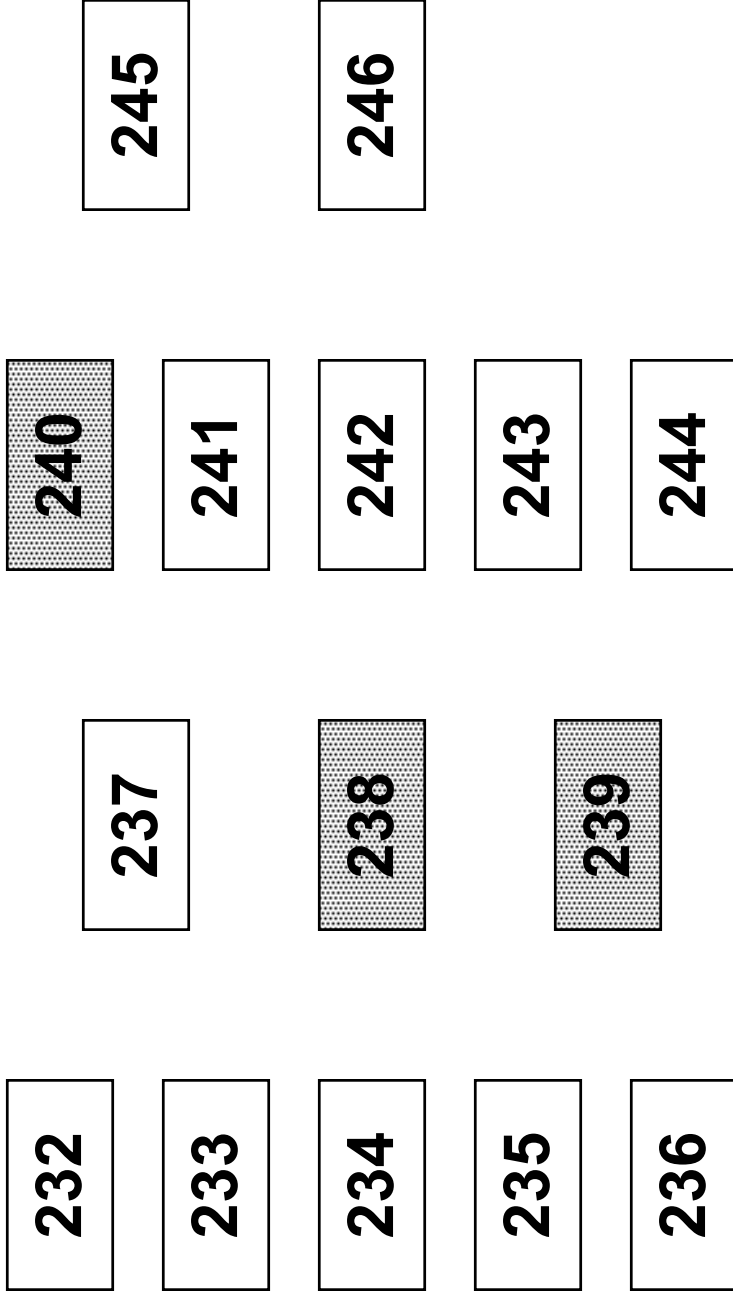
The First Reactor

Chicago Pile 1 (graphite pile)



OT7

Most Predominant Isotopes of Plutonium



Pu-238 Heat-Source Grade

Isotope	Heat-Source	Weapons Grade	Reactor Grade
Pu-238	90.0	<0.05	1.5
Pu-239	9.1	93.6	58.1
Pu-240	0.6	6.0	24.1
Pu-241	0.03	0.4	11.4
Pu-242	<0.01	<0.05	4.9

Pu-239 Weapons Grade

Isotope	Heat-Source	Weapons Grade	Reactor Grade
Pu-238	90.0	<0.05	1.5
Pu-239	9.1	93.6	58.1
Pu-240	0.6	6.0	24.1
Pu-241	0.03	0.4	11.4
Pu-242	<0.01	<0.05	4.9

Pu-240 Reactor Grade

Isotope	Heat-Source	Weapons Grade	Reactor Grade
Pu-238	90.0	<0.05	1.5
Pu-239	9.1	93.6	58.1
Pu-240	0.6	6.0	24.1
Pu-241	0.03	0.4	11.4
Pu-242	<0.01	<0.05	4.9

Physical and Chemical Properties of Plutonium

Density	15.9 - 19.9 g/cm ³ , depending on metal phase. Loose PuO ₂ powder has a density of about 2 g/cm ³ , and sintered pellets have a density of 10.3 - 11.0 g/cm ³ .
Melting point (pure metal)	640° C
Melting point (alloys)	Up to 2000° C, varies with alloy.

Physical and Chemical Properties of Plutonium (cont.)

Boiling point (pure metal)	3327° C
Oxidation rate	Slow in dry air. Rapid under moist conditions or when heated. May result in a low spontaneous ignition temperature.
Action of acids and bases	Dissolves readily in concentrated hydrochloric, hydriodic, and perchloric acids. Partially soluble in most dilute acids; not readily soluble in concentrated sulfuric and nitric acids or sodium hydroxide solutions.

Radiations from Plutonium

- Alpha
- Beta
- Neutron
- Gamma
- X-ray

Contributions to External Exposure Hazards

- **Low energy x-rays**
- **High energy gamma rays**

Typical Gamma Dose Equivalent Rates for 1 kg of Plutonium

Weapons Grade (Pu-239)	↑	1.6-2.3 rem/hr
Reactor Grade (Pu-240)	↑	19-41 rem/hr
Heat-Source Grade (Pu-238)	↑	864 rem/hr

**Typical Neutron Dose
Equivalent Rates for
1 kg of PuO₂**

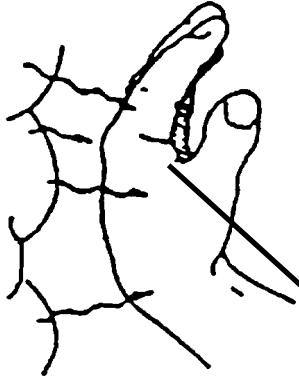
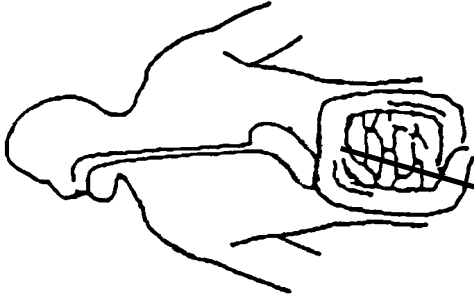
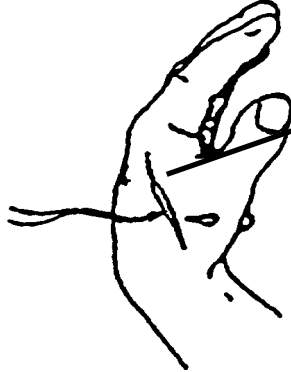
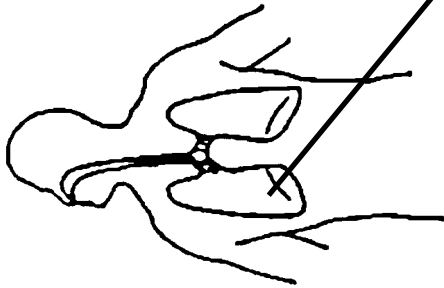
Weapons Grade (Pu-239)	↑	0.3 rem/hr
Reactor Grade (Pu-240)	↑	0.8 rem/hr
Heat-Source Grade (Pu-238)	↑	32 rem/hr

Internal Exposure Hazards

- **An alpha emitter**
- **Approximately 20 times more
damaging than beta radiation**

Modes of Entry

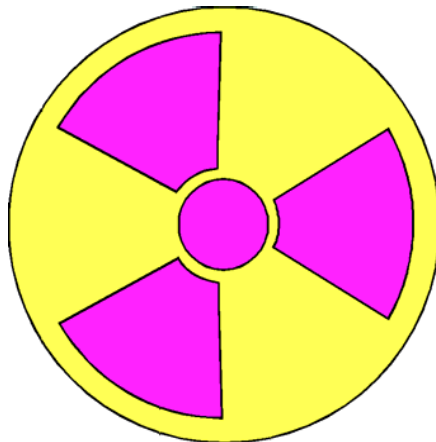
inhalation wound ingestion absorption



bloodstream

Uptakes

- **Distributed to target organs**
- **Slowly eliminated through**
 - **Urine**
 - **Feces**
- **Biological half-life 170-180 years**



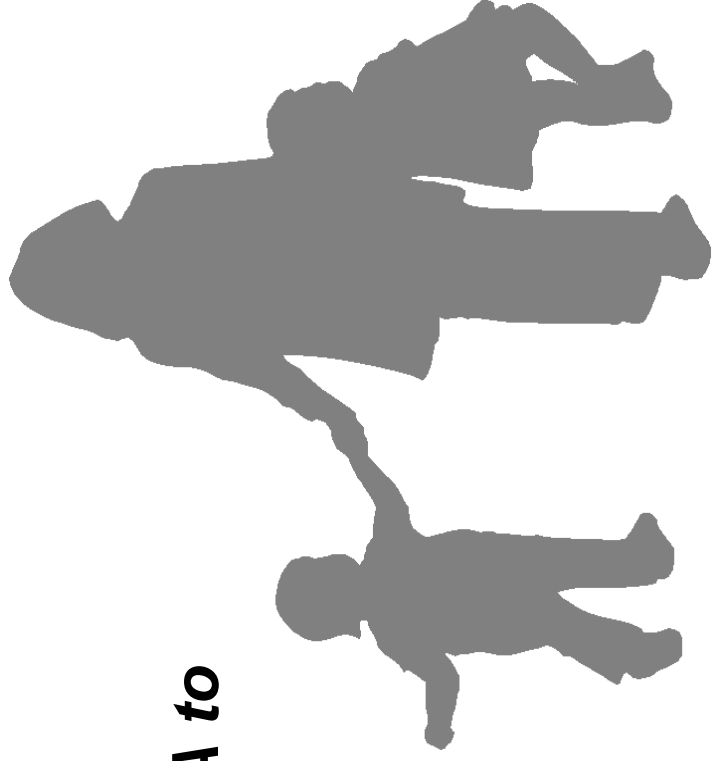
Chelation Therapy

- **Increases solubility of plutonium**
- **Enhances body's ability to eliminate plutonium through urine**
- **DTPA (diethylenetriaminepentaacetic acid)**
 - **Investigational new drug (IND)**
 - **Requires written consent for use**

Two Types of DTPA

- Calcium - DTPA
- Zinc - DTPA

Never give calcium-DTPA to a pregnant woman



Radiological Controls

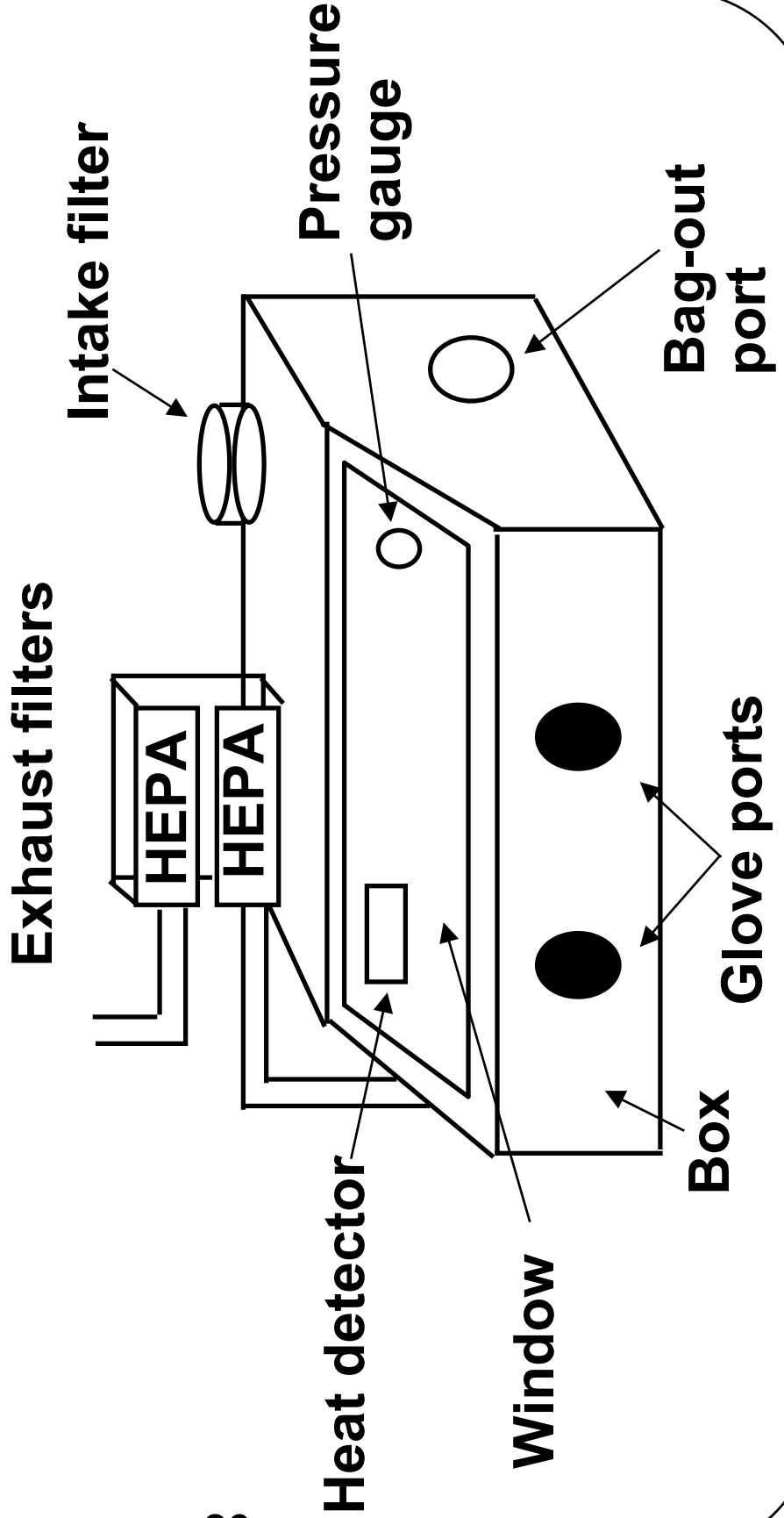
Hierarchy of controls:

- Engineered
- Administrative
- Personnel protection clothing/equipment

External Hazard Controls

- Time - plan ahead
- Distance - farther is better
- Shielding - use lead, steel, water, oil, polyethylene, paraffin
- Source reduction - maintenance is required

Containment



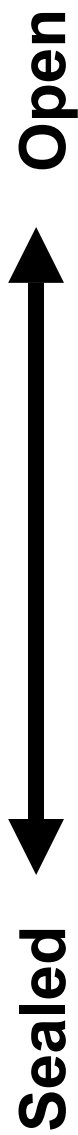
Primary Containment and Confinement

Containments:

- Glove boxes
- Tanks
- Piping

Confinement:

- Fume hoods



Criticality Controls

Examples:

- Piping
- Container shape
- Poisons (neutron-absorbing material)

Fissile Material

- **Made up of heavy atoms**
- **Can be split into pieces emitting energy**
- **Material capable of obtaining criticality**

Administrative Controls

- Posting
- Training
- Housekeeping
- Maintaining access control
- Using Radiation Work Permits
- Stopping work

Surveys for Radiation

- Radiological control surveys
- Radiological control practices
- Portable radiation survey instruments
- Personnel containment monitors
- Airborne radioactivity

Personnel Monitoring

External dosimetry:

- Thermoluminescent dosimeter
 - Beta radiation
 - Gamma radiation
 - X-ray radiation
 - Neutron radiation

Personnel Monitoring

Internal Dosimetry:

Direct:

- Lung counters
- Wound counters

Indirect:

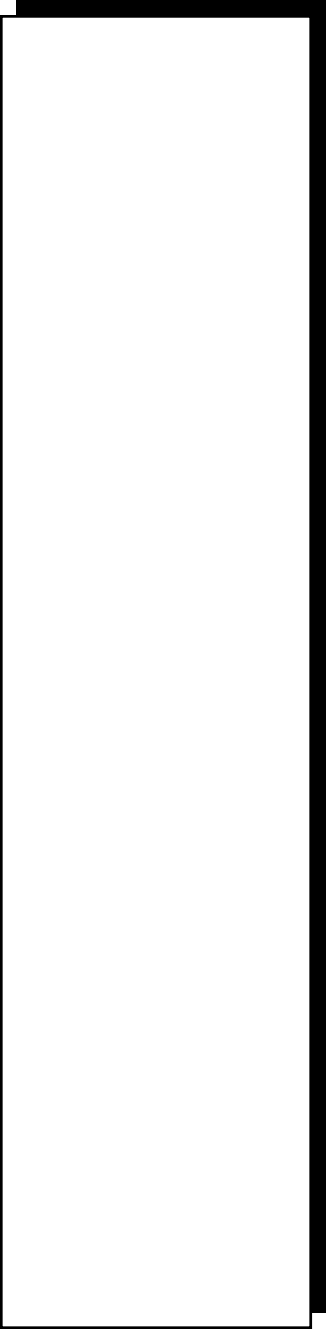
- Bioassays
 - Baseline
 - Routine
 - Non-routine
 - Termination

Abnormal Conditions

- **Fire/explosion**
- **Natural disaster**
- **Plutonium releases**
- **Failure of systems**
- **Other hazards**

Plutonium Facility Fires

- Threaten plutonium
- Burning plutonium
- Exclusion of oxygen
- Rapid heat removal



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I. History of plutonium

A. Discovery

In the earlier part of this century (1900-1940), physicists speculated that there might be elements with higher atomic numbers than uranium (at the time, the element with the highest known atomic number).

The first of these elements was found in 1940 at the University of California (Berkeley) by Edwin M. McMillan and Philip H. Abelson. The element was called neptunium after the planet Neptune. A few months later, Arthur C. Wahl, Glenn T. Seaborg, and Joseph W. Kennedy produced plutonium by bombarding uranium-238 (U-238) with deuterons in an accelerator called a cyclotron (also called an "atom smasher"). The cyclotron is a large machine that uses electromagnets to accelerate charged atomic particles (protons and beta particles) to extremely high speeds and then smash them into a target material.

B. Early research

On March 28, 1941, scientists at the University of California (Berkeley) demonstrated that plutonium-239 (Pu-239) could undergo fission with thermal/slow neutrons. Fission is the process of splitting atoms through which large amounts of energy (200 Mev per fission as compared to 4 ev released during combustion of an atom of carbon) are released, as well as excess neutrons (between two and three), which can then split other atoms to keep a chain reaction going.

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It was soon realized that this "atomic energy" could possibly be used as a weapon. Because of the possibility of using atomic energy for military purposes, the discovery of plutonium was not announced publicly. Further work with plutonium was done in strict secrecy. Although very small quantities of plutonium could be produced in a cyclotron, this method was not capable of producing the large quantities desired for military use.

This problem was solved on December 2, 1942, at the University of Chicago, when a self-sustaining nuclear chain reaction was achieved. By using U-238 atoms to absorb the excess neutrons, plutonium could be produced.

C. Reactor plutonium

Within a few months, two plutonium-producing reactors were built: one in Oak Ridge, Tennessee, and one near Richland, Washington. The actual weapons were built at Los Alamos, New Mexico, which was known as Project Y.

The first atomic bomb (made with plutonium) was detonated in the desert 60 miles northeast of Alamogordo, New Mexico, on July 16, 1945. The atomic age had begun.

More plutonium production reactors were later built at the Savannah River Plant near Aiken, South Carolina, and at the Hanford Engineering Works near Richland, Washington. These sites became the principal sources of plutonium for weapons production in the United States.

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C. Natural plutonium

The half-life of plutonium is so short compared to the age of the earth that if plutonium had existed when the earth was formed, plutonium would not exist today. So, for all practical purposes, plutonium must be man-made.

Remnants of a natural reactor have been discovered in Africa, and it is believed to have operated for millions of years. Very small traces of plutonium have been found in uranium ore, resulting from cosmic-ray produced neutron bombardment of uranium.

II. Nuclides/isotopes and uses of plutonium

A. Predominant plutonium isotopes

Atoms of a specific element can exist in several forms. The difference between the forms is the number of neutrons in the nucleus. These forms are called isotopes of an element. An analogy is that ice cream can come in several flavors, but it is still ice cream. Most elements in nature have several different isotopes. (They have the same number of protons, but a different number of neutrons). Plutonium has 15 isotopes.

Nuclide is a broader term than isotope and refers to any combination of protons and neutrons that exists in more than a transient state. An isotope is a specific combination of protons and neutrons, which defines it as a subset of an element; the two need to be referenced together, such as "an isotope of plutonium."

The predominant nuclides are Pu-238, Pu-239, Pu-240, Pu-241, and Pu-242. Each has a specific application.

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B. Pu-238 – heat-source grade

Heat-source plutonium has the highest Pu-238 content and can be produced by exposing U-235 to neutron bombardment until U-237 is formed. U-237 has a short half-life (6.75 days) and decays to long-lived (2 million years) neptunium-237 (Np-237). Neutron activation of Np-237 produces Np-238, which then decays to Pu-238.

In order for a nuclide to be used for thermal (heat) energy, it must have a half-life greater than 100 days, but less than 100 years. If the half-life is less than 100 days, the nuclide will have to be replenished often. If the half-life is greater than 100 years, the decay rate (activity) will not be high enough to create enough heat to be considered a good heat source.

The half-life of Pu-238 is short enough (88 years) to create a high heat output and long enough to provide long-term power without replenishment. These characteristics make it an ideal heat source for thermoelectric generators. These generators have been used to power ocean buoys and space satellites where long-term, reliable power is essential.

C. Pu-239 – weapons grade

Neutrons absorbed by U-238 atoms cause the formation of U-239, which then decays and eventually forms Pu-239. Pu-239 can fission.

Weapons grade plutonium has the highest content of Pu-239 and is mainly used in nuclear warheads.

D. Pu-240, 241, 242 – reactor grade

In general, the longer Pu-239 remains exposed to neutron bombardment in a reactor, the more Pu-240, Pu-241, and Pu-242 will be produced.

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The actual nuclide and quantity produced depend on the source material, type of reactor, and length of irradiation time.

The reactor grade, with its higher Pu-240 content, presents a much higher gamma and neutron dose rate than does the weapons grade. The reason is that the Pu-240 has more than 1000 times the spontaneous fission rate than does the Pu-239. Pu-241 and Pu-242 also have a much higher spontaneous fission rate. The prompt gammas and neutrons from the spontaneous fission and the fission product gammas produce a much higher overall dose rate for the reactor grade material.

Table 1 shows the approximate weight percentages of the three grades of plutonium.

In November 1946, the first nuclear reactor to use separated out plutonium as fuel, called Clementine, was activated at Los Alamos. Since more plutonium can be bred during the operation of the reactor, the country's nuclear fuel reserves could be greatly increased as a result.

Table 1

Approximate Weight Percentages of Predominant Nuclides			
Nuclide	Heat-Source	Weapons Grade	Reactor Grade
Pu-238	90.0	<0.05	1.5
Pu-239	9.1	93.6	58.1
Pu-240	0.6	6.0	24.1
Pu-241	0.03	0.4	11.4
Pu-242	<0.01	<0.05	4.9

D. Other uses of plutonium

Plutonium can also be used in neutron detectors and neutron sources, as well as in the production of other man-made elements.

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II. Properties of plutonium

A. Physical and chemical

Reactor-produced plutonium goes through several different chemical processes before it becomes a solid metal. Irradiated nuclear fuel elements are dissolved in strong acid and the plutonium is chemically extracted from the solution. Plutonium solutions do not readily create airborne contamination problems, but contamination containment is difficult because of the corrosive nature of the solutions.

The solution is put through another processing stage that converts it from a liquid to a powder. Airborne contamination problems are more likely to occur in this powdered form. Because it is in a more dispersible form, this is done inside gloveboxes.

The powder is then placed in a crucible mold and heated without melting until it becomes a solid metal. The metal has a bright, silver-like appearance at first, but it oxidizes very quickly to a dull gray. It is about as hard and brittle as gray cast iron unless it is alloyed with other metals to make it soft and ductile. Although it is a metal, it is not a good conductor of heat or electricity like most other metals.

There are two difficult conditions that need to be dealt with in the processing:

- It takes tons of irradiated uranium in order to extract grams of plutonium.
- Intense radiation is present in the production, processing, storage, and waste handling. To protect workers, these processes are performed within shielded cubicles or some other shielded containment.

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Table 2 contains a brief summary of some of the features of this metal.

Table 2

Physical and Chemical Properties of Plutonium	
Density	15.9-19.9 g/cm ³ , depending on metal phase. Loose PuO ₂ powder has a density of about 2 g/cm ³ , and sintered pellets have a density of 10.3-11.0 g/cm ³ .
Melting point (pure metal)	640° C
Alloys	Up to 2000° C; varies with alloy.
Boiling point (pure metal)	3327° C
Oxidation rate	Slow in dry air. Rapid under moist conditions or when heated. May result in a low spontaneous ignition temperature.
Action of acids and bases	Dissolves readily in concentrated hydrochloric, hydriodic, and perchloric acids. Attacked by most dilute acids; not readily attacked by concentrated sulfuric and nitric acids or sodium hydroxide solutions.

B. Reactivity

Plutonium metal has proven to be quite pyrophoric under certain conditions. It reacts with oxygen very slowly in dry air, but rapidly in moist conditions, or when the metal is heated.

A pyrophoric reaction can happen with larger pieces of plutonium; however, fire is more likely to occur when the plutonium is in a more dispersed form, such as chips, powder, or turnings. For this reason, it is handled in a moisture-free (dry air) or oxygen-free (inert) atmosphere. Note: With an atmosphere that contains only 5% oxygen, the metal will burn easily. However, when the oxygen content is reduced to 1%, a fire will not continue to burn unless heat is supplied.

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Gloveboxes with dry air or inert atmospheres are still not suitable for long-term storage. Long-term storage of Pu-239 is accomplished by placing the metal in a sealed can, which is usually placed inside one or more cans. As the plutonium decays, the can may build up pressure due to accumulation of helium from the alpha particles and from radiolysis of impurities. The cans are monitored for "bulging" so they can be repacked before the pressure builds up and the cans burst. Long-term storage of plutonium will be in cans developed by DOE for the complex. These are called 3013 cans and are being used by five sites at present.

Pu-238 can generate enough heat to require handling with insulated gloves (or another insulator) and packaging in special containers that dissipate heat. If Pu-238 is stored next to flammable material, a fire may result. If it is stored near material that degrades by heat, flammable or explosive gases may be formed.

There can be other factors that involve fires, such as different alloys that burn or impurities that may be pyrophoric. Highly pure plutonium metal will burn without producing a flame.

C. Radioactivity

All 15 nuclides of plutonium are radioactive and have an atomic number of 94. This means plutonium has 94 protons and is a transuranic element, one of the heaviest elements known. Any element with a higher atomic number than uranium (atomic number 92) is called a transuranic element. Physicists continue to produce these elements, and at present the Eighth Edition of the Table of Isotopes lists elements through 111. In August 1999 physicists reported production of a new element 118 (and its daughter 116) by colliding intermediate mass ions. Transuranic elements are usually referred to as "TRU" elements.

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Plutonium emits one or more of the following types of radiation: alpha, beta, neutron, gamma, and x-ray. The half-lives of nuclides range from 21 minutes for Pu-233 to 80 million years for Pu-244.

Alpha radiation and low-energy (less than 70 keV) beta radiation will not penetrate the dead layer of skin and present no external hazard. These become hazardous when they are introduced inside the body, where they have direct contact with living cells.

With plutonium, neutron radiation is the most penetrating and can be a significant biological hazard.

Most x-ray and/or gamma radiation from plutonium is of lower energy, ranging from 17-20 keV, and is moderately penetrating. This radiation becomes a concern mostly with those handling the material.

There is an additional radiological problem with Pu-241. It is impossible to separate plutonium nuclides to 100% purity; there is always some Pu-241 present. The Pu-241 decays to americium-241 (Am-241). Am-241 emits a higher-energy gamma ray, which is a concern. This americium "in growth" results in increasing radiation levels for many years. This can contribute to significant doses, since some applications may have 30%-50% Pu-241.

D. Criticality

While several plutonium nuclides can fission, only Pu-239 is of practical importance as a criticality concern. A criticality accident involves an uncontrolled chain reaction that releases large quantities of heat, neutrons, and gamma radiation. It does not create an atomic explosion. Facilities that possess fissile material have criticality detection systems to warn workers of an event. Remember, if a criticality accident does occur, exit as quickly and safely as possible. **JUST GET OUT!**

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IV. External and Internal Hazards

A. External exposure hazards

1. Alpha radiation

Alpha radiation is not an external dose concern because it will not penetrate the dead layer of skin. Alpha radiation is primarily a concern if it is introduced inside the body.

2. Gamma and x-ray radiation

All plutonium nuclides emit large quantities of low-energy x-rays, and the "in growth" of Am-241 emits higher-energy gamma rays. These contribute to external exposure and especially extremity exposure.

3. Neutron radiation

- Several plutonium nuclides emit neutron radiation through spontaneous fission (notably from Pu-238, Pu-240, and Pu-242). The rate at which these neutrons are emitted is different with different nuclides of the plutonium.
- Neutron radiation is also produced by an alpha-neutron reaction. When alpha particles interact with the nucleus of an atom of a lighter element (such as beryllium or lithium), the nucleus is left in an excited state. To return to the ground state, the atom emits a neutron with an energy of about 2.5 MeV.
- An alpha particle emitted by a plutonium atom may penetrate the nucleus of a fluorine atom in the compound PuF₄. The excited nucleus decays by emitting a neutron. The neutron yield and energy of the alpha-neutron reaction are dependent on the alpha energy and the material.

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4. Criticality

- A criticality event can produce a life-threatening dose of radiation to those who are in the immediate vicinity.
- Example: A burst of 10^{18} fissions in a metal system may produce doses of 600 rad up to a distance of 30 feet and 100 rad up to around 70 feet (assuming there is no shielding). Also, there may be enough heat generated to melt the system containing the plutonium. The fission products produced will create residual contamination and lasting radiation problems.
- LD_{50/30}: lethal dose at which 50% of an irradiated population dies with 30 days.

B. Internal exposure hazards

Plutonium is a heavy metal that is chemically toxic as well as radioactive. Many other heavy metals such as arsenic, lead, and uranium are also chemically toxic.

Plutonium is primarily an alpha emitter and is particularly hazardous if taken into the body. Alpha particles do not travel far in material, which means they lose all of their energy in a short distance. Alpha particles cannot penetrate the dead layer of skin on the body. However, when they are in direct contact with our living cells, such as in our lungs, they are a hazard. Other alpha emitters include natural radon, which is also an inhalation concern.

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V. Modes of Exposure and Treatment

A. Modes of exposure

Plutonium may enter the body by the following modes:

1. Inhalation (breathing)

For plutonium (and many other radionuclides, as well) inhalation is the most common route of intake into the body. To determine the level of airborne radioactivity that workers are exposed to occupationally, air samples are routinely collected and analyzed at DOE plutonium facilities. The resulting concentration (in units of activity per volume) is compared to a guideline value known as the derived air concentration (DAC). If a worker were to breathe one Pu-238 DAC ($2E-12$ uCi/ml for class W) for one working year (2000 hours), at the end of the year, the committed dose equivalent (summed over 50 years) would be 50 rem to the critical organ (bone surfaces). This would equate to a committed effective dose equivalent of 1.5 rem, if the smaller doses to the other organs are neglected.

An occupied area containing airborne concentrations of radioactivity that exceed or are likely to exceed the DAC values provided in Appendices A and C of 10 CFR 835 or if an individual could receive an intake exceeding 12 DAC-hours in a week must be posted as an "Airborne Radioactivity Area" according to 10 CFR 835 and the RadCon Standard. Posting the area would, in turn, necessitate a consideration of respiratory protection.

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2. Injection (through wounds)

Although inhalation is the most common mode of intake, injection through wounds can be very hazardous. In these cases, large amounts of radioactive or toxic material could be deposited directly into the body and then absorbed into the bloodstream.

3. Ingestion (eating or drinking)

Ingestion through eating or drinking is very rare and usually only happens when there is contamination around the nose or mouth. Depending on the chemical composition, up to 99.9% of the plutonium can pass through the body and be eliminated.

4. Absorption (skin contact)

Absorption is extremely rare and is not a real concern except when using plutonium hexafluoride or acidic solutions that may contact and burn the skin.

B. Intakes

Although operations are planned and precautions are taken to avoid any significant intake of radioactive materials, the possibility of an intake always exists. When plutonium gets into the body, it will be distributed to various organs, depending on its physical and chemical makeup.

Particles that are inhaled and deposited in the lungs may stay there for years. During this time, they could be slowly absorbed into the bloodstream (as is the case with insoluble plutonium oxide). Soluble plutonium is absorbed into the bloodstream much more rapidly.

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Once in the bloodstream (whether inhaled or injected), plutonium will distribute to certain target organs, such as bone surfaces, the liver, and, to a lesser extent, the gonads. After plutonium reaches these organs, it is eliminated extremely slowly through the feces and urine. The biological half-life of plutonium is 170-180 years. Biological half-life is the time required for the body to eliminate one-half of the uptake.

Because plutonium may remain in the body for a long time and the alpha energy is fairly high, target organs can receive large (greater than 50 rem) doses over time.

C. Medical treatment

1. Chelation therapy

Chelation therapy is recommended for plutonium inhalation. It is also recommended for injections through wounds, and excision may also be necessary.

Chelating agents are drugs that increase the solubility of plutonium and enhance the body's ability to eliminate it through the urine.

DTPA (diethylenetriaminepentaacetic acid) is generally more effective than other chelating agents. It is not a new drug and has been used on hundreds of individuals. However, because there is no commercial use for DTPA, it is categorized as an Investigational New Drug (IND). Because it is an IND, a consent form must be signed prior to administering it.

There are two primary types of DTPA: calcium-DTPA (Ca-DTPA) and zinc-DTPA (Zn-DTPA). Ca-DTPA is more effective than Zn-DTPA in the first 24 hours. Because it depletes more of the heavy metals in the body (such as iron or zinc), it is not recommended for long-term treatment.

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To avoid long-term depletion, Ca-DTPA is administered initially, then followed with Zn-DTPA. Ca-DTPA should never be used in the treatment of pregnant women since it could cause birth defects.

Substantial dose reductions can be achieved if DTPA is administered within a few hours (recommended within one hour) of the intake. Dose reductions from 10% to 90% have been achieved for wound or burn cases and up to 30% for inhalation cases

2. Excision

Because it is difficult to detect contamination in an injection/wound, a radiation measurement instrument called a wound counter is used. If the wound counter reveals contamination, excision is sometimes recommended. Excision is the surgical removal of contaminated tissue.

If a large amount of contamination is located at the wound site, excision can dramatically reduce the exposure. Dose reductions of up to a factor of 100 have been achieved with excision.

Usually, only a small amount of tissue is removed. This does not present a significant health hazard.

VI. Radiological Controls

A. Hierarchy of controls

The preferred hierarchy of controls is listed below:

- Engineered
- Administrative
- Personnel protective clothing/equipment

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1. Engineered controls are built into the system. Engineered controls include shielding, ventilation, and containment systems.
 2. Administrative controls for plutonium facilities are the same as any other radiation source.
 3. Personnel protective clothing/equipment
- B. External hazard controls
1. Time – plan ahead to avoid spending any more time near radiation sources than necessary.
 2. Distance – the further from the radiation source, the lower the dose. Example: With a point source, if the distance to the source is decreased by one-half, the dose will increase by four times.
 3. Shielding – plutonium emits low-energy x-ray and gamma radiation that is easily shielded with small amounts of steel or lead. Also, the use of lead-lined glovebox gloves helps reduce extremity dose for those who handle plutonium.

In a plutonium facility, shielding for neutrons must be addressed as well as shielding for x-ray and gamma radiation. Neutrons are more penetrating and they are harder to shield. The most effective shielding employs materials that have hydrogen, such as water, oil, polyethylene, or paraffin. Many gloveboxes will have hollow walls and windows filled with one of these substances. But caution must be exercised in the use of these highly flammable hydrocarbon products.

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4. Source reduction – the source of the radiation can be reduced by decontamination, better storage methods, or elimination of the source altogether. Extremity dose can be reduced by periodically sweeping/wiping the plutonium dust from the inside of the gloveboxes and gloves.

Protective clothing, commonly of Tyvex material, is used to keep contamination off personal clothing and skin. It does not stop the external radiation exposure (except alpha rays), but it helps prevent the spread of contamination both onto and into the body.

C. Internal hazard controls

During operations in which there is a potential to breach a containment system (such as glove changes or seal-outs) and create airborne radioactivity, respiratory protection is the primary method of preventing internal dose from inhalation. To minimize the possibility of inhalation, individuals must ensure the physical integrity of the respirator, obtain a good seal, and ensure the protection factor of the respirator is adequate.

There are also methods to prevent injection wounds (such as placing leather gloves over glovebox gloves or ensuring there are no sharp objects inside containments). If personnel have any suspicion of an injection wound, they should immediately seek the assistance of the site radiological control organization.

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1. Containment

Because plutonium is of particular concern if inhaled, special precautions are taken to avoid airborne contamination. There are many different types of containments that, when used in conjunction with ventilation, help prevent the loss of material and thus minimize dose to the workers.

Gloveboxes are almost always used when handling plutonium in a dispersible form. However, properly vented hoods are acceptable for handling the very small quantities used in a research laboratory. Proper hood design is critical for plutonium and only very small quantities should be used.

Gloveboxes, tanks, and piping are examples of "primary containments," because there are no system openings. Gloveboxes have ports with long plastic sleeves attached that allow material to be "sealed in" or "sealed out" from the glovebox without breaching the containment.

Types of equipment such as fumehoods are "primary confinements," since they are the barrier closest to the source. Primary barriers require good ventilation to maintain contamination control. **Do not insert your hands into a primary barrier unless you have been trained and authorized to do so.**

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The room that encloses the primary system and is intended to provide containment if the primary fails is called secondary containment. The building that encloses the systems is the final barrier.

2. Ventilation

Maintaining proper airflow is essential for the safe operation of a plutonium facility. Air flows from regions of high pressure to regions of low pressure. Ventilation systems are engineered so that air flows from areas of low contamination to areas of greater contamination. Air balance is maintained by using damper controls, air locks, and backup safety systems. Air balance is also maintained by controlling the position of the inside doors. **Ventilation control doors should not be blocked open, or ventilation balance could be lost. Also, do not operate any equipment unless you have been trained and authorized to do so.**

Devices such as tents or glovebags are used to provide local containment for maintenance activities. These containments normally have local ventilation and exhaust filtration. A bagless transfer system for moving items out of gloveboxes has been developed for use throughout the complex.

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The best way to maintain contamination control after a loss of containment is to decontaminate to low or non-detectable levels. However, in some instances, contamination must be fixed in place. This is usually done by painting the surfaces of gloveboxes, walls, floors, etc. Because there is a potential for contamination control problems if these surfaces are disturbed, individuals should not scrape surfaces or remove tape unless precautions are taken.

D. Criticality controls

Many facility-specific engineered and administrative controls have been put in place in an effort to prevent an uncontrolled criticality. This course does not provide adequate training in the handling of fissile material. Examples of engineered controls are specific piping, container shape, and poisons (neutron-absorbing material). Examples of administrative controls are procedures on container spacing and the amount of material in the container.

Only workers who are properly trained should handle fissile material. If you are not trained as a fissile material handler, **do not**, under any circumstances, handle fissile material.

Because liquid containing plutonium is a special criticality concern, care must be taken when handling plutonium-bearing liquids. Containers that could hold liquid must not be placed in or under gloveboxes or hoods unless they are criticality safety approved.

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E. Administrative controls

There are many administrative controls to reduce doses. The following are just a few that should apply to all sites:

- Posting
- Training
- Housekeeping
- Maintaining access control
- Using Radiation Work Permits
- Stopping work

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VII. Radiological surveys and monitoring at plutonium facilities

A. Surveys

1. Radiological control surveys

In order to maintain good radiological controls, the radiological control organization establishes a program to periodically survey most areas in the buildings. Rooms are not the only things surveyed. Equipment (such as gloveboxes and gloves, hoods, and piping) is also included. A good radiological control program aids in early detection of contamination.

2. Radiological control practices

Personnel who work with or around plutonium should perform periodic surveys. For instance, when working in gloveboxes, personnel should check periodically (every 15-30 minutes) to ensure that there has been no compromise of the port gloves by monitoring their hands and arms on radiation detection instruments. If contamination is found, they should survey any area of the body that may have been contaminated (such as the hands, arms, chest, or face).

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3. Portable radiation survey instruments

- Alpha

Because alpha particles travel only a short distance in air (typically less than 1 inch), surveying for alpha radiation is more difficult than for beta or gamma radiation. Proper survey techniques require that the probe be held close to the surface (approximately one-fourth of an inch). The survey speed has to be slow (1-2 inches per second).

Alpha radiation can be shielded with a thin film of water or dirt; therefore, care must be taken when performing surveys. Because of possible water shielding, personnel must not be perspiring and material must be dry.

- Beta

One type of portable survey meter is designed to measure both beta and gamma radiations. A sliding shield is used to differentiate between them (closed for gamma measurements). Like alpha counting, the distance at which measurements is made is important.

- Gamma

Because of the low energy of the gamma radiation, not all dose rate instruments can be used. Due to the low energy, radiation levels may drop off rapidly in a short distance, causing these instruments to have readings lower than the actual surface dose rate.

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- Neutron

Be aware that it is possible to have a neutron dose rate when there is little or no gamma dose rate. Therefore, special surveys for neutrons may need to be done in areas where gamma radiation fields would be expected.

4. Personnel contamination monitors

Personnel survey instruments are usually placed at the exits from radiologically controlled areas. Personnel frisking shall be performed after removal of protective clothing and prior to washing and showering. The use of a personnel contamination monitor (such as a portal monitor or hand and foot counter), if available, is encouraged by the RadCon Standard. Personal items such as notebooks, papers, flashlights, shall be subjected to the same frisking.

5. Airborne radioactivity

- Continuous air monitors (CAMs)

It is important to alert workers when airborne radioactivity levels rise because inhalation is the most common pathway into the body.

CAMs collect radioactive material from the air over an extended period of time and measure the activity. If a CAM activates in the room you are in, LEAVE as quickly and as safely as possible. Get at least one air space away (next room or farther) from the alarm and notify the site radiological control organization immediately.

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- Fixed air samplers

Facilities are required to sample the air in areas where an individual is likely to receive an exposure of 40 or more DAC-hours in a year. Real-time air monitoring shall be performed to detect and provide warning of airborne radioactivity concentrations that warrant immediate action to terminate inhalation of airborne radioactive material. Fixed air samplers are used in these areas (they may also be in areas with CAMs). They are sensitive to low levels of airborne radioactivity (they are capable of determining a fraction of a DAC), but do not have alarm capabilities to alert workers to airborne radioactivity.

- Breathing zone

Airborne radioactivity is easily influenced by air currents, and air samplers (fixed or CAMs) should be strategically placed to represent the workers' "breathing zone." The breathing zone is the air space where the workers will be breathing the air. If the air samplers are not located in the breathing zone, a worker could receive internal contamination with no indication from the air monitoring systems.

- Lapel air samplers

Lapel air samplers are small battery-powered devices, attached to workers' lapels, that draw air through a filter to collect radioactive particulates for determination of the air concentration breathed by the worker.

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B. Personnel monitoring

1. External dosimetry

The most common device used to monitor worker dose is the thermoluminescent dosimeter (TLD). Dosimeters can be configured to monitor beta, gamma, x-ray, and neutron radiation.

Supplemental dosimeters (TLDs in finger rings or wrist bands) may also be worn for monitoring extremity dose.

There are dosimeters and gamma pencils equipped with alarms that can be used, but they must be specially made for low-energy gamma rays. Nuclear accident dosimeters (NADs) are required for facilities with sufficient quantities of plutonium to form a critical mass. They are issued to personnel and are also stationed throughout the facility. They contain different types of materials that become radioactive through neutron activation. The neutron dose is determined by evaluating the amount of activation of the NAD material.

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2. Internal dosimetry

Indication of internal exposure is achieved through many different methods. For instance, nasal smears are used to indicate exposure to airborne radioactivity. The presence of contamination in the nose is a good indicator that the worker inhaled radioactive material. However, it is common knowledge that the absence of contamination in the nose does not prove an intake did not occur. If there is a positive indication, other methods are used to measure how much plutonium has been taken into the body.

- Direct measurements

Plutonium's low-energy x-rays and gamma radiation (17-20 keV) are not readily detected. However, the decay product, Am-241, emits gamma radiation (60 keV) that can be detected with specially designed detectors. Lung counters are special detectors that are placed over the lungs to determine the amount of radioactive material in the lungs.

Wound counters are devices that can estimate the amount of plutonium in injections/wounds. They are small detectors that are placed directly over the wound.

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- Indirect measurements

Bioassays are used to determine internal uptakes of plutonium. Urine and/or fecal samples are collected, reduced chemically, and counted for the plutonium content. Baseline bioassays are performed prior to beginning a new job to find out if the worker already has incorporated radionuclides. Termination bioassays are performed to document if any radionuclides have been incorporated during the work assignment that is completed.

Routine bioassays are performed to verify the effectiveness of workplace controls and to identify workers who may have had an intake, whereas non-routine bioassays are done after a suspected intake of plutonium is identified. Baseline bioassays are performed before a worker begins a new job to find out if he has a deposition of plutonium. Termination bioassays are performed when a worker stops work or leaves his job to find out if he has a deposition of plutonium and if so, to calculate his dose.

Soluble plutonium retained in the body is excreted mainly through the urine. Following an incident, fecal sampling is done. These samples are more sensitive as to intake, but less of a quantitative indicator of plutonium uptake.

VIII. Response to abnormal conditions

A. Unexpected adverse situations

To properly deal with unexpected adverse situations in a plutonium facility, a well-developed program and trained personnel should be in place.

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B. Abnormal conditions could include the following:

- Fires/explosions
- Natural disasters
- Plutonium releases
- Failure of systems (e.g., ventilation)
- Other hazards

C. Fire safety

Because of the inhalation hazard, fires in plutonium facilities require particular care.

It is important to distinguish between fires that threaten to involve plutonium and those in which the plutonium is burning. For plutonium metal, complete exclusion of oxygen and/or rapid heat removal are the only truly effective means to extinguish fires. Due to reactivity and criticality concerns, water may not be the appropriate extinguishing agent for a fire, as it acts as a moderator and may lead to criticality. Fire systems are therefore tailored to the facility situation.

Good housekeeping is more than keeping things picked up and in their assigned place to reduce tripping hazards and present a pleasant work environment and a better appearance to inspectors. Consideration must also be given to combustible loading and the storage and use of combustible and flammable materials. The quantity of chemicals and all materials should be minimized, as these contribute to fire initiation, reactions, fire intensity, waste production, and spread of contamination.

D. Facility alarms

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Handouts



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Lessons Learned 1
Internal Doses Exceeding Regulatory Limit

On March 16, 2000, an airborne release of plutonium-238 occurred near a glovebox in the Plutonium Processing and Handling Facility (TA-55) of the Los Alamos National Laboratory (ALA-LA-LANL-TA55-2000-0009). The first indication of a release was when the hand monitor on the glovebox being examined by an electrical technician alarmed. Then a second hand monitor on the associated dropbox alarmed. Radiological Control Technicians believed the alarms to be spurious and tried to reset them. A third hand monitor on a nearby glovebox alarmed and almost simultaneously a continuous air monitor (CAM) in a corner of the room alarmed. In less than a minute all four CAMs in the room had alarmed. In addition, CAMs in two adjacent rooms alarmed. All personnel in the room evacuated to the hallway.

On scene surveys of the eight affected workers revealed contamination on anti-contamination clothing up to 140,000 dpm and skin contamination up to 20,000 dpm. Decontamination of the workers was completed within 30 minutes. Nasal smears were taken before decontamination and sent to the Health Physics Analytical Laboratory. Five of the workers had positive smears and management decided to send all of them for medical follow-up. The four workers with the highest results were offered chelation therapy to accelerate removal of plutonium from their bodies and all signed consent forms. Intravenous administration of diethylenetriaminepentaacetic acid (DTPA) was then completed for each. Preliminary estimates of the committed effective dose equivalent (CEDE) for the four most highly exposed workers gave 300 rem to the most highly exposed worker and >5 rem for the other three.

The accident occurred when an electrical/mechanical technician attempted to determine why the argon flow bubbler to the glovebox was not working. While he was examining the piping under the glovebox, the monitors alarmed. It was subsequently found that a Teflon gasket in the airlock had failed due to radiation degradation and the piping had not been adequately secured at one of the fittings.

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Lessons Learned 2
Glovebox Glove Failure

An employee at the Plutonium Processing and Handling Facility at Los Alamos National Laboratory detected contamination on the right elbow of his anti-contamination coveralls after moving equipment in a glovebox (ALO-LA-LANL-TA55-1999-0015). A Radiological Control Technician surveyed the employee and found contamination on the employee's upper left cheek, left eyebrow, forehead and hair. The maximum contamination detected was 4,000 dpm alpha. The employee was decontaminated with one soap and water wash. Diagnostic bioassay sampling revealed no uptake.

Contamination was detected in the lefthand glove of the glovebox where the employee had been working. There was no obvious sign of glove failure in the gloves which had been replaced one month earlier and had been inspected prior to use on the day of the incident. This shows the importance of monitoring with an alpha detector at intervals during the day.

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Lessons Learned 3
Worker Sustains Finger Laceration While Working in Glovebox

An employee at the Rocky Flats Plant was cutting a furnace inside a glovebox to reduce its size for waste disposal when he accidentally hit the trigger on the electric saw and the blade cut his left index finger (RFO-KHLL-779OPS-1999-0006). A bag was placed over the lacerated hand and taped at the wrist. The employee was transported to Occupational Medicine, where a wound counter measured 41 nanocuries alpha. After decontamination, 30.5 nanocuries was measured. A decision was made by medical personnel to offer the employee diethylenetriaminepentaacetic acid ((DTPA), a chelating agent. The employee consented to chelation therapy and DTPA was administered. Upon further examination, medical personnel found a tendon that appeared to have been damaged. The employee, accompanied by two radiological control technicians and the plant physician, was transported to a specialist for tendon repair.

The committed effective Dose Equivalent (CEDE) was determined to be 3,100 millirem and maximum committed organ dose (bone surfaces) was 56,000 millirem. Due to the administration of DTPA, the urine sample results collected prior to April 8, 1999 were not used in this assessment. The urine sample results collected after April 8, 1999 and three fecal samples collected in February 1999 were used to calculate the intake and resulting dose.

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Lessons Learned 4
Employee sustains Finger Laceration While Working in Glovebox

An employee at the Plutonium Processing and Handling Facility at Los Alamos National Laboratory was disassembling a sample cutter in a glovebox when he accidentally cut his left little finger (ALO-LA-LANL-TA55-2000-0005). The lid of the sample cutter was made of plastic which had become brittle from irradiation, and when the employee folded it in half, it shattered into small pieces. When the employee passed the lid through a transfer box, a small piece pierced his lefthand glovebox glove, his protective glove and the skin of his little finger.

A survey of the employee's finger indicated 1,000 dpm alpha, but wound counting of the puncture area after decontamination indicated no detectable radioactivity. Nasal smears were negative.

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**Lessons Learned 5
Criticality Accident at Fuel Fabrication Plant**

The criticality accident that occurred in September 1999 at the Fuel Conversion Test Building in Tokai-mura, Japan, was the first in which measurable exposures occurred to off-site members of the public. Two operators lost their lives and another received a significant dose. The excursion continued for nearly twenty hours before it was terminated by workers directed by government officials.

There were two deviations from the license-authorized procedures that caused the accident. First, the company procedures specified that the dissolution step was to be conducted in open, 10-liter stainless steel buckets instead of the dissolution vessel. The much more serious procedural departure was the transfer of the nitrate solution into the unfavorable geometry precipitation vessel instead of the prescribed geometry columns.

Factors contributing to the accident include a weak understanding by personnel at all levels of the factors that influence criticality, and specifically, a lack of realization that the 45 liters of solution, while far subcritical in the intended storage tanks, could be supercritical in the unfavorable geometry precipitation vessel. Secondly, there was a mind-set at the plant and the regulatory authority that a criticality accident was not a credible event.

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Review Activity:

<u>DOE</u>	<u>Operations Offices</u>	<u>National Laboratories</u>	<u>Facilities</u>
DP EH	AL ID NV RL	ORNL Sandia	Bechtel BWXT Idaho Pantex

Preparing Activity:

DOE-EH-52

Project Number:

TRNG-0016

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