

**Radiological Control Technician Training  
Site Academic Training Instructor's Guide Phase I**



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

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**Course Title:** Radiological Control Technician  
**Module Title:** Radiological Documentation  
**Module Number:** 2.01

**Objectives:**

- 2.01.01 List the types of records/reports that the Radiological Control group is responsible for maintaining at your site.
- 2.01.02 Describe the types of records and reports used at your site by the Radiological Control Group, to include but should not be limited to:
  - a. Radiological Work Permits
  - b. Survey Reports
  - c. Analysis Reports
  - d. Radiological Deficiency Reports
  - e. ALARA Documentation
  - f. Exposure Reports
- 2.01.03 Explain the requirements for the records management system, such as QC, auditability/retrievability, management information at your site.

**References:**

1. 10 CFR Part 835 (2007) "Occupational Radiation Protection".
2. "Radiological Control Standard," DOE-STD-1098-2008.

**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

A good Radiological Control Program must have a sound documentation process. RCTs are involved daily in creating records through surveys, RWPs, and procedures that give a history of actual conditions and operations.

## C. Module Overview

1. Purpose and requirements
2. Radiological records management program
3. Radiological record keeping standards
4. Types of radiological records
5. Records management
6. Radiological reporting

## D. Introduce Objectives

**II. MODULE OUTLINE**

O.H.: Objectives

NOTE: Most of the material for this section will come from specific site procedures. The instructor must be thoroughly knowledgeable in and have available for student use, procedures for RWP's, Radiological Occurrences, Records Maintenance, Inventories, and

any other RC procedure related to administration. In addition, any other procedure or procedural change can be covered in this section.

#### A. Purpose/Requirements

Discuss the purpose and requirements for records and reports at DOE facilities based on 10 CFR 835 and DOE RCS. Discuss any additional site requirements.

#### B. Radiological Records Management Program

1. Discuss the types of radiological records that should be included in the records management program.

- a. Quality Control
- b. Audits
- c. Records retrieval
- d. Management information

Objective 2.01.01

0. (Insert site specific information here.)

#### C. Radiological Record Keeping Standards

2. List the standards for record keeping.
3. Discuss the justifications for record keeping standards.

Ask the students why it is considered necessary to include facility, specific location and function on documentation. Ask trainees why it makes sense to initial and date corrections.

#### D. Types of Radiological Records

1. Identify and define the record categories:
  - a. Employment History Records

- b. Personnel Radiological Records
  - c. Medical Records
  - e. Radiological Training and Qualification Records
  - f. Instrumentation and Calibration Records
  - g. Radiological Control Procedures
  - 2. (Insert site specific information here.)
- E. Records Management Objective 2.01.02
- 4. Discuss storage requirements
  - 5. (Insert site specific information here.)
- F. Radiological Exposure Reports Objective 2.01.03
- 1. Purpose
  - 2. Process
  - 3. Examples of filled-out exposure reports

### III. SUMMARY

- A. Review major points
  - 0. Purpose and requirements
    - 1. Radiological records management program
    - 2. Radiological record keeping standards
    - 3. Types of radiological records
    - 4. Records management
    - 5. Radiological reporting
- B. Review learning objectives



#### **IV. EVALUATION**

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.

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**Course Title:** Radiological Control Technician  
**Module Title:** Communication Systems  
**Module Number:** 2.02

**Objectives:**

- 2.02.01 Explain the importance of good communication.
- 2.02.02 Identify two methods of communication and be able to determine different types of each.
- 2.02.03 Describe different types of communication systems.
- 2.02.04 Describe the FCC and DOE guidelines regarding proper use of communication systems.
- 2.02.05 Describe general attributes of good communications.
- 2.02.06 Explain the importance of knowing how to contact key personnel.
- 2.02.07 Identify the communication systems available at your site and methods available to contact key personnel.
- 2.02.08 Describe the emergency communication systems available at your site.

**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Recommended - radio, telephone, pager, warning alarms, phonetic alphabet handout
5. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

Good communication skills are essential to an RCT. Each RCT should develop an ability to communicate using both verbal and non-verbal media. This skill will ensure important information is transmitted to the proper individuals in a clear and concise manner.

## C. Overview of Lesson

1. Importance of communication
2. Methods of communication
3. Communication systems
4. FCC and DOE guidelines
5. General attributes of good communications
6. Contact of key personnel
7. Site communication systems
8. Site emergency communications

## D. Introduce Objectives

O.H.: Objectives

**II. MODULE OUTLINE**

- |  |   |
|--|---|
| <ul style="list-style-type: none"> <li>A. Importance of Communications           <ul style="list-style-type: none"> <li>1. Clear</li> <li>2. Understood</li> <li>3. Received</li> </ul> </li> <li>B. Two Methods of Communication           <ul style="list-style-type: none"> <li>1. Verbal</li> <li>2. Nonverbal</li> </ul> </li> <li>C. Communication Systems           <ul style="list-style-type: none"> <li>1. Public Address</li> <li>2. Telephones</li> <li>3. Two-way Radios</li> <li>4. Pagers</li> <li>5. Computer Mail Systems</li> <li>6. Computer Bulletin Boards</li> </ul> </li> <li>D. FCC and DOE Guidelines           <ul style="list-style-type: none"> <li>1. When using communication systems licensed by the Federal Communications Commission and operated by the Department of Energy, one cannot: Stress importance of complying with these restrictions.               <ul style="list-style-type: none"> <li>a. Use profane, indecent, or obscene language.</li> </ul> </li> </ul> </li> </ul> | <p>Objective 2.02.01</p><br><p>Objective 2.02.02</p> <p>Ask the student to name the two ways to communicate and examples.</p><br><p>Objective 2.02.03</p> <p>Ask students to name communication systems available in everyday use at home and work.</p><br><p>Objective 2.02.04</p> |
|--|---|

- b. Willfully damage or permit radio equipment damage.
- c. Cause malicious interference with any radio communications.
- d. Intercept and use or publish the contents of any radio message without the permission of the proper authorities.
- e. Make unnecessary or unidentified transmissions.
- f. Transmit without first making sure that the transmission will not cause harmful interference.
- g. Make any adjustments, repairs, or alterations to a radio transmitter without licensing by the FCC or acceptable equivalent.
- h. Transmit a call sign, letter, or numeral which has not been assigned to your station.
- i. Rebroadcast another transmission (i.e., radio station music).

E. General Attributes of Good Communications

- 1. Minimize the use of abbreviations and acronyms.
- 2. Make all oral instructions clear and concise.
- 3. Ensure the identity of the person(s) is/are clearly understood.
- 4. Use clear, precise terminology.
- 5. Repeat back messages, either paraphrased or verbatim.
- 6. Speak distinctly and deliberately.

Objective 2.02.05

Stress importance of good habits and technique.

See Table 1 - "Phonetic Alphabet and Numbers".

7. Acknowledge all communications.

F. Contacting Key Personnel

Objective 2.02.06

1. Getting knowledgeable people to locations is necessary for routine, emergency, and non-routine circumstances.
2. Important for the protection of personnel, equipment and to prevent radiological releases.
3. RCTs should be aware of communication equipment.

G. Site Communication Systems

Objective 2.02.07

(Insert site specific information here.)

H. Emergency Communication Systems

Objective 2.02.08

(Insert site specific information here.)

### III. SUMMARY

A. Review major topics

1. Importance of communication
2. Methods of communication
3. Communication systems
4. FCC and DOE guidelines
5. General attributes of good communications
6. Contact of key personnel
7. Site communication systems
8. Site emergency communication

B. Review learning objectives

#### **IV. EVALUATION**

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.



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**Course Title:** Radiological Control Technician  
**Module Title:** Counting Errors and Statistics  
**Module Number:** 2.03

**Objectives:**

- 2.03.01. Identify five general types of errors that can occur when analyzing radioactive samples, and describe the effect of each source of error on sample measurements.
- 2.03.02. State two applications of counting statistics in sample analysis.
- 2.03.03. Define the following terms:
  - a. mode
  - b. median
  - c. mean
- 2.03.04. Given a series of data, determine the mode, median, or mean.
- 2.03.05. Define the following terms:
  - a. variance
  - b. standard deviation
- 2.03.06. Given the formula and a set of data, calculate the standard deviation.
- 2.03.07. State the purpose of a Chi-squared test.
- 2.03.08. State the criteria for acceptable Chi-squared values at your site.
- 2.03.09. State the purpose of creating quality control (QC) charts.
- 2.03.10. State the requirements for maintenance and review of QC charts at your site.
- 2.03.11. State the purpose of calculating warning and control limits.
- 2.03.12. State the purpose of determining efficiencies and correction factors.
- 2.03.13. Given counting data and source assay information, calculate efficiencies and correction factors.
- 2.03.14. State the meaning of counting data reported as  $x \pm y$ .
- 2.03.15. Given counting results and appropriate formulas, report results to desired confidence level.
- 2.03.16. State the purpose of determining background.
- 2.03.17. State the method and requirements for determining background for counting systems at your site.
- 2.03.18. State the purpose of performing sample planchet maintenance.

- 2.03.19. State the method and requirements for performing planchet maintenance for counting systems at your site.
- 2.03.20. Explain methods to improve the statistical validity of sample measurements.
- 2.03.21. Define "detection limit," and explain the purpose of using detection limits in the analysis of radioactive samples.
- 2.03.22. Given the formula and necessary information, calculate detection limit values for counting systems at your site.
- 2.03.23. State the purpose and method of determining crosstalk.
- 2.03.24. State the criteria for acceptable values of crosstalk for counting systems at your site.
- 2.03.25. State the purpose of performing a voltage plateau.
- 2.03.26. State the method of performing a voltage plateau on counting systems at your site.

**References:**

1. Chase & Rabinowitz, "Principles of Radioisotope Methodology," 3rd Edition, Burgess Publishing, 1987.
2. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5<sup>th</sup> ed.; Pacific Radiation Corporation; 2008.
3. "Radiation Detection and Measurement"; Knoll, Glenn F.; Wiley & Sons; 2000.
4. "Webster's New World Dictionary," 4rd College Edition, Webster's New World, Cleveland & New York, 1999.
5. Moe, Harold, "Operational Health Physics Training," ANL-88-26; DOE; Argonne National Laboratory, Chicago, 1988.

**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

Radiological sample analysis involves observation of a random process, one that may or may not occur, and estimation of the amount of radioactive material present based on that observation. All over the country radiological control personnel are using the activity measurements to make decisions that may affect the health and safety of workers at those facilities and their surrounding environments.

O.H.: Objectives

## C. Overview of Lesson

1. This unit will present an overview of measurement processes, and statistical evaluation of both measurements and equipment performance.
2. In addition, this unit will address some of the actions to take to minimize the sources of error in count room operations.

## D. Introduce Objectives

**II. MODULE OUTLINE**

## A. General Sources of Error

Assuming the counting system is calibrated correctly, there are five general sources of error associated with counting a sample: self-absorption, backscatter, resolving time, geometry, and random disintegration (of radioactive atoms).

1. Self-absorption
  - a. When a sample has an abnormally large amount of material on the sample media, it could introduce a counting error due to self-absorption, with is absorption of the emitted radiation by the sample material itself.

- b. Self-absorption could occur for:
    - 1) Liquid samples with a high solid content
    - 2) Air samples from a high dust area
    - 3) Use of improper filter paper may introduce a type of self-absorption, especially in alpha counting (i.e., absorption by the media, or filter).
  - c. Personnel counting samples should ensure the correct sample media is used, and that the sample does not become too heavily loaded with sample material.
  - d. Count room personnel should be routinely checking samples for improper media or heavily loaded samples.
2. Backscatter
- a. Counting errors due to backscatter occur when the emitted radiation traveling away from the detector is reflected, or scattered back to the detector, by the material in back of the sample.
  - b. The amount of radiation that is scattered back will depend upon the type and energy of the radiation and the type of backing material (reflector).
  - c. The amount of backscattered radiation increases as the energy of the radiation increases and as the atomic number of the backing material increases.
  - d. Generally, backscatter error is only a consideration for particulate radiation, such as alpha and beta particles. Because beta particles are more penetrating than alpha particles, backscatter error will be more pronounced for beta radiation.
  - e. The ratio of measured activity of a beta source counted with a reflector compared to counting the same source without a reflector is called the backscatter factor (BF).

$$BF = \frac{\text{counts} - \text{with} - \text{reflector}}{\text{counts} - \text{without} - \text{reflector}}$$

- f. Normally, backscatter error is accounted for in the efficiency or conversion factor of the instrument.
- g. However, if different reflector materials, such as aluminum and stainless steel, are used in calibration and operation, an additional unaccounted error is introduced.
- h. This additional error will be about 6% for stainless steel versus aluminum. Count room personnel must be aware of the reflector material used during calibration of the counting equipment.
- i. Any deviation from that reflector material will introduce an unaccounted error and reduce confidence in the analysis results.

### 3. Resolving Time

- a. Resolving time is the time interval which must elapse after a detector pulse is counted before another full-size pulse can be counted.
- b. Any radiation entering the detector during the resolving time will not be recorded as a full size pulse; therefore, the information on that radiation interaction is lost.
- c. As the activity, or decay rate, of the sample increases, the amount of information lost during the resolving time of the detector is increased.
- d. As the losses from resolving time increase, an additional error in the measurement is introduced. Typical resolving time losses are shown in Table 1 of the Study Guide.
- e. Resolving time losses can be corrected by using the equation:

Refer students to Table 1 in Study Guide.

$$R = \frac{R_o}{1 - R_o \tau} \quad (\text{Eq.2})$$

where:  $R$  = "true" count rate, in cpm  
 $R_o$  = observed count rate, in cpm  
 $\tau$  = resolving time of the detector, in minutes ("tau")

- f. Count room personnel should be aware of the limitations for sample count rate, based upon procedures and the type of detector in use, to prevent the introduction of additional resolving time losses. This is especially true for counting equipment that uses GM detectors.

#### 4. Geometry

- a. Geometry related counting errors result from the positioning of the sample in relation to the detector.
- b. Normally, only a fraction of the radiation emitted by the sample is emitted in the direction of the detector because the detector does not surround the sample.
- c. If the distance between the sample and the detector is varied, then the fraction of emitted radiation which hits the detector will change.
- d. This fraction will also change if the orientation of the sample under the detector (i.e., side-to-side) is varied.
- e. An error in the measurement can be introduced if the geometry of the sample and detector is varied from the geometry used during instrument calibration.
- f. This is especially critical for alpha counting where any change in the sample to detector distance also increases or decreases the chance of shielding the alpha particles by the air between the sample and detector.
- g. Examples of geometry-related errors are:
- 1) Piling smears and/or filters on top of each other in the same sample holder. Piling of the samples moves the top sample closer to the detector and varies the calibration geometry.
  - 2) Using deeper or shallower sample holders than

those used during calibration changes the sample-to-detector distance.

- 3) Adjusting movable bases in the counting equipment sliding drawer changes the sample to detector distance.
- 4) Using too many or not using the appropriate sample holder or planchet changes the sample to detector distance. Sources not fixed in position can change can change geometry and reduce reproducibility.
- 5) Plexiglass shelving in counting chamber is improperly set.

#### 5. Random disintegration

The fifth source of general counting error is the random disintegration of the radioactive atoms and constitutes the remainder of the lesson.

#### B. Statistics

1. Statistics is a branch of mathematics that deals with the organization, analysis, collection, and interpretation of statistical data.
2. No definition of statistical data is given. However, Webster's does define a statistic as "an estimate of a variable, as an average or a mean, made on the basis of a sample taken from a larger set of data."
3. This last definition is applicable to our discussion of counting statistics. After all, when we take samples, we use the data derived from analysis of those samples to make determinations about conditions in an area, in water, or in air, etc., assuming that the sample is representative.
4. So, we have estimated conditions (a variable) on the basis of a sample (our smear, water sample, air sample) taken from a larger set of data.
5. Over the years, various methods and observations have identified three models which can be applied to observations of events that have two possible outcomes (binary processes).
7. Luckily, we can define most observations in terms of two possible outcomes. (See table 2).

Refer students to  
Table 2



7. For each of the processes that we want to study, we have defined a trial (our test), a success and a failure (two possible outcomes), and have determined the probability of observing our defined success.
8. Now, to study these processes, we can use proven, statistical models to evaluate our observations for error.
9. Consider the possibilities when throwing two dice. There are 36 possible outcomes when throwing two dice, as indicated in Table 3.
10. If, in our study of this process, we define a success as throwing a number between 2 and 12, the outcome is academic. All trials will be successful, and we can describe the probabilities of throwing any individual number between the range of 2 and 12 inclusive would add up to 1.
11. If we define a success as throwing a particular number, we can define the probability of our success in terms of the number of possible outcomes that would give us that number in comparison to the total number of possible outcomes.
12. If we were to take two dice, roll the dice a large number of times, and graph the results in the same manner, we would expect these results to produce a curve such as the one should in Figure 1.
13. The area under the curve can be mathematically determined and would correspond to the probability of success of a particular outcome.
14. For example, to determine the probability of throwing a particular number between 2 and 12 we would calculate the area under the curve between 2 and 12. The results of that calculation would be 36.
15. This is what statistics is all about; random binomial processes that should produce results in certain patterns that have been proven over the years.
16. The three models that are used are distribution functions of binomial processes with different governing parameters. These functions and their restrictions are:

Refer students to Figure 1 in Study Guide.

## a. Binomial distribution

- 1) This is the most general of the statistical models and is widely applicable to all processes with a constant probability.
- 2) It is not widely used in nuclear applications because the mathematics are too complex.

## b. Poisson distribution

- 1) A simplified version of binomial distribution is the Poisson (pronounced "pwusówn") distribution, which is valid when the probability of success,  $P(x)$ , is small.
- 2) If we graphed a Poisson distribution function, we would expect to see the predicted number of successes at the lower end of the curve, with successes over the entire range if sufficient trials were attempted.
- 3) Thus, the curve would appear as seen in Figure 2.
- 4) The Poisson model is used mainly for applications involving counting system background and detection limits, where the population (i.e., number of counts) is small.

Refer students to Figure 2 in Study Guide.

This will be discussed in greater detail later.

## c. Gaussian distribution

- 1) Also called the "normal distribution," the Gaussian (pronounced "Gowziun") distribution is a further simplification which is applicable if the average number of successes is relatively large, but the probability of success is still low.
- 2) Note that the highest number of successes is at the center of the curve, the curve is a bell shaped curve, and the relative change in success from one point to the adjacent is small.
- 3) Also note that the mean, or average number of successes, is at the highest point, or at the center of the curve.

Refer students to Figure 3 in Study Guide

- 4) The Gaussian, or normal, distribution is applied to counting applications where the mean success is expected to be greater than 20.
  - a) It is used for counting system calibrations and operational checks, as well as for normal samples containing activity.
  - b) It may or may not include environmental samples (i.e., samples with very low activity).

Objective 2.03.02

#### 17. Application of Statistical Models

Application of specific statistical methods and models to nuclear counting operations is termed counting statistics and is essentially used to do two things:

- a. Predict the inherent statistical uncertainty associated with a single measurement, thus allowing us to estimate the precision associated with that measurement.
- b. Serve as a check on the normal function of nuclear counting equipment.

Objective 2.03.03

#### 18. Definitions

- a. Mode - An individual data point that is repeated the most in a particular data set.
- b. Median - The center value in a data set arranged in ascending order.
- c. Mean - Average value of all the values in the data set.

#### 19. Determination of mode, median and mean

Objective 2.03.04

- a. Determination of the Mode: In the set of test scores in Figure 4, a score of 95 occurs (i.e., is repeated) more often than any other score.
- b. Determination of the Median: In the same set of test scores, this is the score in the middle - where one half of the scores are below, and the other half are above the median. The median for the test scores is 90.

Refer students to Figure 4 in the Study Guide.

- c. Determination of the Mean: This is found by adding all of the values in the set together, and dividing by the number of values in the set. The mean of the test scores is 89. Mean determination is often expressed using special symbols, as illustrated in the following equation:

$$\bar{x} = \frac{\sum x_i}{n} \quad (\text{Eq. 3})$$

where:  $\bar{x}$  = mean (sometimes pronounced "x bar")

$x_i$  = data point with index  $i$

$n$  = number of data points

$\Sigma$  = summation symbol

$$\sum_{i=1}^n x_i = x_1 + x_2 + x_3 + \dots + x_n$$

## 20. Variance and Standard Deviation

Using the Gaussian distribution model depicted in Figure 5 of the Study Guide, we need to define the terms "variance" and "standard deviation" which are both used as descriptors of the spread of the population (or the data set) in a normal distribution.

### a. Variance

Objective 2.03.05 a.

- 1) The amount of scatter of data points around the mean is defined as the sample variance.
- 2) In other words, it tells how much the data "varies" from the mean.

### b. Standard deviation

Objective 2.03.05 b.

- 1) A more precise term is the standard deviation, represented by  $\sigma$  (pronounced "sigma").
- 2) Mathematically, in a normal distribution, the standard deviation is the square root of the variance.
- 3) The standard deviation of a population is defined mathematically as:

Objective 2.03.06

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n}} \quad (\text{Eq.4})$$

where:  $\sigma$  = biased standard deviation of the population

$x_i$  = sample counts for each data point

$\bar{x}$  = mean

$n$  = number of data points

- 4) If most of the data points are located close to the mean, the curve will be tall and steep and have a low numerical value for a standard deviation.
- 5) If data points are scattered, the curve will be lower and not as steep and have a larger numerical value for a standard deviation.
- 6) In a Gaussian distribution, it has been determined mathematically that 68.2% of the area under the curve falls within the data point located at the mean  $\pm$  (plus or minus) one standard deviation ( $1 \sigma$ ); 95.4% of the area under the curve falls between the data point located at  $\pm$  two standard deviations ( $2 \sigma$ ), etc.
- 7) What this means to us in terms of counting processes is that if the distribution (as depicted in Figure 5) is representative of a counting function with a mean observable success  $>20$  (Gaussian distribution):
  - a) 68.2% of the time the observed successes (or counts) will be within  $\pm 1$  standard deviation of the mean.
  - b) 95.4% of the time the observed successes (or counts) will be within  $\pm 2$  standard deviations of the mean.
  - c) 99.97% of the time the observed successes (or counts) will be within  $\pm 3$  standard deviations of the mean.
- 8) Remember, the area of the curve represents the

probability of success in a random process. In radiation protection this random process is the decay of a radioactive sample.

9) The known statistical distribution is used in radiation protection when setting up a counting system and in evaluating its operation by means of daily pre-operational source checks.

10) In performing the calibration of the system, a radioactive source with a known activity is counted twenty times for one minute each time.

11) Using the data from the twenty counts, the mean and standard deviation can be calculated.

a) The mean can then be used to determine the efficiency of the system while allowing for a certain number of standard deviations during operation.

b) The twenty counts can also be used to perform another required test of the system's performance, the Chi-squared test.

Refer students to Example 1 in Study Guide.

#### 21. Chi-squared Test

Objective 2.03.07

- a. The Chi-squared test (pronounced "ki") is used to determine the precision of a counting system.
  - 1) Precision is a measure of exactly how a result is determined without regard to its accuracy.
  - 2) It is a measure of the reproducibility of a result, or in other words, how often that result can be repeated, or how often a "success" can be obtained.
- b. This test results in a numerical value, called the Chi-squared value ( $X^2$ ) which is then compared to a range of values for a specified number of observations or trials.
- c. This range represents the expected (or predicted) probability for the chosen distribution.

- 1) If the  $X^2$  value is lower than the expected range, this tells us that there is not a sufficient degree of randomness in the observed data.
  - 2) If the value is too high, it tells us that there is too much randomness in the observed data.
- d. The Chi-squared test is often referred to as a "goodness-of-fit" test. It answers the question: How well does this data fit a Poisson distribution curve?
  - e. If it does not fit a curve indicating sufficient randomness, then the counting instrument may be malfunctioning.
  - f. The Chi-squared value is calculated as follows:

$$X^2 = \frac{\sum (x_i - \bar{x})^2}{\bar{x}} \quad (\text{Eq.5})$$

Refer students to Example 2 in Study Guide.

- g. Criteria for acceptable Chi-squared values:

(Insert site specific information here.)

Assuming a given set of data passes the Chi-squared test, the data can then be used to prepare quality control charts for use in verifying the consistent performance of the system.

Objective 2.03.08

### C. Quality Control Charts

1. Quality control charts are prepared using source counting data obtained during system calibration. The source used for daily checks should be identical to the one used during system calibration.
2. Obviously since this test verifies that the equipment is still operating within an expected range of response, we cannot change the conditions of the test in mid-stream.
3. QC charts, then, enable us to track the performance of the system while in use.

Objective 2.03.09

4. Data that can be used for quality control charts include gross counts, counts per unit time, and efficiency. Most nuclear laboratories use a set counting time corresponding to the normal counting time for the sample geometry being tested.  
  
If smears are counted for one minute, then all statistical analysis should be based on one-minute counts.
5. When the system is calibrated and the initial calculations performed, the numerical values of the mean  $\pm$  1, 2, and 3 standard deviations are also determined.
6. Using standard graph paper, paper designed specifically for this purpose, or a computer graphing software, lines are drawn all the way across the paper at those points corresponding to the mean, the mean plus 1, 2, and 3 standard deviations, and the mean minus 1, 2, and 3 standard deviations. The mean is the center line of the paper.
7. Quality control charts should be maintained in the area of the radioactivity counting system such that they will be readily accessible to those who operate the system.
8. These charts can then be used by operators to determine if routine periodic checks (typically daily) have been completed before system use.

(Insert site specific information here.)

Objective 2.03.10

Objective 2.03.11

9. System Operating Limits
  - a. The values corresponding to  $\pm 2$  and  $\pm 3$  standard deviations are called the lower and upper warning and control limits, respectively.
  - b. The results of the daily source counts are graphed daily in many countrooms.
  - c. Most of the time our results will lie between the lines corresponding to  $\pm 1$  standard deviation (68.2%).
  - d. We also know that 95.4% of the time our count will be between  $\pm 2$  standard deviations and that 99.97% of the time our count will be between  $\pm 3$  standard deviations.
  - e. Counts that fall outside the warning limit ( $\pm 2 \sigma$ ) are



not necessarily incorrect. Statistical distribution models say that we should get some counts in that area.

- 1) Counts outside the warning limits indicate that something may be wrong.
- f. The same models say that we will also get some outside the control limits ( $\pm 3 \sigma$ ). However, not very many measurements will be outside those limits.
  - g. We use  $3 \sigma$  as the control, a standard for acceptable performance. In doing so we say that values outside of  $\pm 3 \sigma$  indicate unacceptable performance, even though those values may be statistically valid.
  - h. True randomness also requires that there be no patterns in the data that are obtained; some will be higher than the mean, some will be lower, and some will be right on the mean.
  - i. When patterns do show up in quality control charts, they are usually indicators of systematic error. For example:
    - 1) Multiple points outside two sigma
    - 2) Repetitive points ( $n$  out of  $n$ ) outside one sigma
    - 3) Multiple points, in a row, on the same side of the mean
    - 4) Multiple points, in a row, going up or down.
  - j. The assumption is made that systematic error is present in our measurements, and that our statistical analysis has some potential for identifying its presence.
  - k. However, industry assumption is that systematic error that is present is very small in comparison to random error.

#### D. Counter Efficiency

Objective 2.03.12

1. A detector intercepts and registers only a fraction of the total number of radiations emitted by a radioactive source.
2. The major factors determining the fraction of radiations

emitted by a source that are detected include:

- a. The fraction of radiations emitted by the source which travel in the direction of the detector window
  - b. The fraction emitted in the direction of the detector window which actually reach the window
  - c. The fraction of radiations incident on the window which actually pass through the window and produce an ionization
  - d. The fraction scattered into the detector window
3. All radiation detectors will, in principle, produce an output pulse for each particle or photon which interacts within its active volume.
  4. The detector then would be said to be 100 percent "efficient," because 100 percent of the activity was detected and reported.
  5. In practice, because of the factors outlined above, the actual (or total) activity emitted from the source is not detected.
  6. Therefore, there is only a certain fraction of the disintegrations occurring that results in counts reported by the detector.
  7. Using a calibrated source with a known activity, a precise figure can be determined for this fraction.
  8. This value can then be used as a ratio in order to relate the number of pulses counted to the number of particles and/or photons incident on the detector.
  9. This ratio is called the efficiency.

It can also be referred to as the detector yield, since the detector yields a certain percentage of the actual counts.

10. The detector efficiency gives us the fraction of counts detected per disintegration, or  $c/d$ .
11. Since activity is the number of disintegrations per unit time, and the number of counts are detected in a finite time, the two rates can be used to determine the efficiency if both rates are in the same units of time.

12. Counts per minute (cpm) and disintegrations per minute (dpm) are the most common.
13. Thus, the efficiency,  $E$ , can be determined as shown in Equation 6. Used in this manner the time units will cancel, resulting in counts/disintegration (c/d).

Objective 2.03.13

$$E = \frac{cpm}{dpm} = \frac{c}{d} \quad (\text{Eq.6})$$

- a. The efficiency obtained in the formula above will be in fractional or decimal form.
- b. To calculate the percent efficiency, the fraction can be multiplied by 100.
- 1) For example, an efficiency of 0.25 would mean  $0.25 \times 100$ , or 25%.

Review Example 3 in Study Guide with students.

14. By algebraic manipulation, Equation 6 can be solved for the disintegration rate (see Equation 7).
15. The system efficiency is determined as part of the calibration. When analyzing samples, a count rate is reported by the counting system.
16. Using Equation 7, the activity ( $A$ ) of the sample can then be determined in dpm, and then converted to any other units of activity (e.g., Ci, Bq).

$$dpm = \frac{cpm}{E} \longrightarrow A_{dpm} = \frac{cpm}{E} \quad (\text{Eq.7})$$

Review Example 4 in Study Guide with students.

17. As seen in Equation 7 above, the net count rate is divided by the efficiency.

18. A correction factor (CF), which is simply the inverse of the efficiency, is used by multiplying it by the net count rate to determine the activity, as in Equation 8.

$$CF = \frac{1}{E} \quad (\text{Eq.8})$$

Review Example 5 in Study Guide with students.

19. This count-rate correction factor should not to be confused with a geometry correction factor used with some radiation instruments, such as the beta correction factor for a Cutie Pie (RO-3C).

#### E. Error Calculations

1. The error present in a measurement governed by a statistical model can be calculated using known parameters of that model.
2. Nuclear laboratories are expected to operate at a high degree of precision and accuracy. However, since we know that there is some error in our measurements, we are tasked with reporting measurements to outside agencies in a format that identifies that potential error.
3. The format that is used should specify the activity units and a range in which the number must fall. In other words, the results would be reported as a given activity plus or minus the error in the measurement.
4. Since nuclear laboratories prefer to be right more than they are wrong, counting results are usually reported in a range that would be correct 95% of the time, or at a 95% confidence level.
5. In order to do this, the reported result should be in the format:

$$x.xx \pm yy (K \sigma) \quad (\text{Eq. 9})$$

where:  $x.xx$  = measured activity, in units of dpm, Ci, or Bq

$yy$  = associated potential (or possible) error in the measurement

$K$  = multiple of counting error

Objective 2.03.14

$\sigma$  = standard deviation at stated confidence level (CL)

Note: Use of  $K\sigma$  is only required for confidence levels other than 68% (see Table 6).

Therefore:

$\sigma$  =  $1 \times \sigma$  68% CL (optional)

$1.64 \sigma$  =  $1.64 \times \sigma$  90% CL (sometimes used)

$2 \sigma$  =  $1.96 \times \sigma$  95% CL (normally used)

6. For example, a measurement of  $150 \pm 34$  dpm ( $2 \sigma$ ) indicates the activity as 150 dpm; however, it could be as little as 116 dpm or as much as 184 dpm with 95% confidence (at  $2 \sigma$ ).
7. The calculations of the actual range of error is based on the standard deviation for the distribution.
8. In the normal (or Gaussian) distribution, the standard deviation of a single count is defined as the square root of the mean, or  $\sigma = \sqrt{x}$
9. The error,  $e$ , present in a single count is some multiplier,  $K$ , multiplied by the square root of that mean, i.e., some multiple times the standard deviation,  $K \sigma$ .
10. The value of  $K$  used is based on the confidence level that is desired, and is derived from the area of the curve included at that confidence level (see Figure 5).
11. Common values for  $K$  are given in Table 4.
12. To calculate the range to the point at which you would expect to be right 95% of the time, you would multiply the standard deviation by 1.96, and report the results of the measurement as  $x.xx$  dpm  $\pm$   $yy$  dpm ( $2 \sigma$ ).
13. Note that using a 68% or 50% confidence level introduces an expected error a large percentage of the time. Therefore, for reasonable accuracy a higher confidence level must be used.

Refer students to Table 4 in Study Guide.

14. The simple standard deviation ( $\sigma$ ) of the single count ( $x$ ) is usually determined as a count rate (counts per unit time). This is done by dividing the count rate ( $R$ ) by the count time ( $T$ ). Subscripts can be applied to distinguish sample count rates from background count rates.

Objective 2.03.15

Review Example 6 in Study Guide with students.

$$\sigma = K \sqrt{\frac{R}{T}} \quad (\text{Eq.8})$$

## F. Background

Objective 2.03.16

### 1. Determination of Background

- a. Radioactivity measurements cannot be made without consideration of the background.
- b. Background, or background radiation, is the radiation that enters the detector concurrently with the radiation emitted from the sample being analyzed.
- c. This radiation can be from natural sources, either external to the detector (e.g., cosmic or terrestrial) or radiation originating inside the detector chamber that is not part of the sample.
- d. In practice, the total counts are recorded by the counter. This total includes the counts contributed by both the sample and the background.
- e. Therefore, the contribution of the background will produce an error in radioactivity measurements unless the background count rate is determined by a separate operation and subtracted from the total activity, or gross count rate.
- f. The difference between the gross and the background rates is called the net count rate (sometimes given units of ccpm, or corrected counts per minute).
- g. This relationship is seen in the following equation:

$$R_S = R_{S+B} - R_B \quad (\text{Eq.11})$$

where:  $R_S$  = net sample count rate (cpm)

$R_{S+B}$  = gross sample count rate (cpm)

$R_B$  = background count rate (cpm)

- h. The background is determined as part of the system calibration by counting a background (empty) planchet for a given time.
- i. The background count rate is determined in the same way as any count rate, where the gross counts are divided by the count time, as seen in Equation 12 below.

$$R_B = \frac{N_B}{T_B} \quad (\text{Eq. 12})$$

where:  $R_B$  = background count rate (counts per time, i.e., cpm)

$N_B$  = gross counts, background

$T_B$  = background count time

- j. For low-background counting systems two background values must be determined: one for alpha and one for beta-gamma.

These two values are used to determine background alpha and beta-gamma sample count rates, respectively, during calibration and when analyzing samples.

- k. In practice, background values should be kept as low as possible.

As a guideline, background on automatic counting systems should not be allowed to exceed 0.5 cpm alpha and 1 cpm beta-gamma.

## 2. Reducing background

- a. Typically, the lower the system background the more reliable the analysis of samples will be.
- b. In low-background counting systems the detector housing is surrounded by lead shielding so as to reduce the background.

- c. Nonetheless, some background still manages to reach the detector. Obviously, little can be done to reduce the actual source of background due to natural sources.

On many systems a second detector is incorporated to detect penetrating background radiation. When a sample is analyzed the counts detected by this second detector during the same time period are internally subtracted from the gross counts for the sample.

- d. Background originating inside the detector chamber can be, for the most part, more easily controlled. The main contributors of this type of background are:
  - 1) Radiation emitted from detector materials
  - 2) Radioactive material on inside detector surfaces
  - 3) Radioactive material on the sample slide assembly
  - 4) Contamination in or on the sample planchet or planchet carrier
- e. There are, unfortunately, trace amounts of radioisotopes in the materials of which detectors and their housings are made. This is simply a fact of life in the atomic age.
  - 1) However, the contribution to background from this source is negligible, but should nonetheless be acknowledged.
- f. Radioactive material can be transferred from contaminated samples to the inside surfaces of the detector chamber during counting.
  - 1) This usually occurs when samples having gross amounts of material on them are counted in a low background system.
  - 2) During the insertion and withdrawal of the sample into the detector chamber, loose material can be spread into the chamber.
  - 3) In order to prevent this, these samples should be counted using a field survey instrument or a mini-scaler.



- 4) Low-background systems are designed for counting lower-activity samples. Counting of a high-activity sample on these systems should be avoided unless it is a sealed radioactive source.
  
- g. Radioactive material can also be transferred from contaminated samples to the slide assembly upon which samples are inserted into, and withdrawn from, the detector chamber.
  - 1) This can be prevented in the same way as stated above. In addition, when loading and stacking samples for counting, ensure that the slide assembly cover is in place.
  - 2) The slide assembly should also be cleaned on a routine basis (e.g., weekly).
  
- h. When loading and unloading samples into and from planchets, material from the samples can be spread to the planchet and/or the carrier.
  - 1) Most smears and air samples are 47-mm diameter and are counted in a planchet that is almost the same size.
  - 2) The planchet is placed in a carrier which surrounds and supports the planchet and allows for automatic sample exchange by the counting system.
  - 3) When a sample is counted, the entire carrier is placed under the detector window inside the detector chamber.
  - 4) Any contamination on the carrier (or in the planchet) is counted with, and attributed to, the sample.
  - 5) A paper disc can be placed in the bottom of the planchet as a step in preventing transfer of material from samples to the planchet.
  - 6) Care should be taken when loading and unloading samples such that material remains on the sample media.

(Insert site specific information here.)

3. Planchet maintenance

Objective 2.03.17

- a. Planchets and carriers should be inspected, cleaned, and counted on a routine basis.

Objective 2.03.18

- 1) All in-use planchets and carriers must read less than established site limits.
- 2) Planchets exceeding these limits should be decontaminated and recounted as necessary.

- b. By maintaining planchets clean and as free from contamination as possible, sample result reliability will be increased because the amount of error introduced in the sample analysis will be reduced.

(Insert site specific information here.)

Objective 2.03.19

G. Propagation of Error

1. The error present in a measurement includes the error present in the sample count, which contains both sample and background, and the error present in the background count.

Rules for propagation of error preclude merely adding the two errors together.

2. The total error in the measurement is calculated by squaring the error in the background and adding that to the square of the error in the sample count, and taking the square root of the sum, as shown in Equation 13.

$$e_s = \sqrt{e_{S+B}^2 + e_B^2} \quad (\text{Eq.13})$$

where:  $e_s$  = error present in the measurement (sample)

$e_{S+B}$  = error in sample count (sample plus background)

$e_B$  = error present in background count

3. Since we normally use this equation in terms of a count rate, the formula is slightly modified as follows, and the error stated as the sample standard deviation ( $\sigma_s$ ):

$$K\sigma_S = K\sqrt{\frac{R_{S+B}}{T_S} + \frac{R_B}{T_B}} \quad (\text{Eq.14})$$

- where:  $R_{S+B}$  = gross sample count rate (sample plus background)  
 $R_B$  = background count rate  
 $T_S$  = sample count time  
 $T_B$  = background count time  
 $K$  = confidence level multiple (see Table 4)

4. The error in the sample count is the standard deviation of the count, which is the square root of that count (see Equation 13 above). If we square a square root we get the number we started with.
5. If the sample counting time and the background counting time is the same, the formula can be simplified even more to:

$$K\sigma_S = K\sqrt{\frac{R_{S+B} + R_B}{T}} \quad (\text{Eq.15})$$

Review Example 7 in Study Guide with students.

Review Example 8 in Study Guide with students.

#### H. Improving Statistical Validity of Count Room Measurements

1. Minimizing the statistical error present in a single sample count is limited to several options. If we look at the factors present in the calculation below (same as Equation 14), we can see that there are varying degrees of control over these factors.
2. The standard deviation is calculated here in terms of count rate.

Objective 2.03.20

$$\sigma_{rate} = \sqrt{\frac{R_{S+B}}{T_S} + \frac{R_B}{T_B}}$$

- a.  $R_{S+B}$  is the sample count rate. We really have no control over this.
- b.  $R_B$  is the background count rate. We do have some control over this.

- 1) On any counting equipment the background should be maintained as low as possible.
  - 2) In most of our counting applications, however, the relative magnitude of the background count rate should be extremely small in comparison to the sample count rate if proper procedures are followed.
  - 3) This really becomes an issue when counting samples for free release or environmental samples.
  - 4) However, some reduction in error can be obtained by increasing the background counting time, as discussed below.
- c.  $T_B$  and  $T_S$  are the background and sample counting times, respectively. These are the factors that we have absolute control over.
- 1) In the previous section we talked about the reliability of the count itself. We have been able to state that a count under given circumstances may be reproduced with a certain confidence level, and that the larger the number of counts the greater the reliability.
  - 2) The condition we have been assuming is that our count is taken within a given time. In order to get more precise results, many counts must be observed. Therefore, if we have low count rates, the counting time must be increased in order to obtain many counts, thereby making the result more precise (or reproducible).
- d. The total counting time required depends upon both the sample and background count rates.
- 1) For high sample activities the sample count time can be relatively short compared to the background count time.
  - 2) For medium count rates we must increase the sample count time in order to increase precision.
  - 3) As the sample activity gets even lower, we approach the case where we must devote equal time to the background and source counts.

- a) In other words, by counting low activity samples for the same amount of time as that of the background determination, we increase the precision of our sample result.
  - b) However, we must never count a sample for a period of time longer than that of the system background.
3. In summary, by minimizing the potential error present, we improve statistical validity of our measurements.

#### I. Detection Limits

1. The detection limit of a measurement system refers to the statistically determined quantity of radioactive material (or radiation) that can be measured (or detected) at a preselected confidence level.

Objective 2.03.21

This limit is a factor of both the instrumentation and technique/procedure being used.

2. The two parameters of interest for a detector system with a background response greater than zero are:
  - a.  $L_C$  Critical detection level: the response level at which the detector output can be considered "above background"
  - b.  $L_D$  Minimum significant activity level, i.e., the activity level that can be seen with a detector with a fixed level of certainty
3. These detection levels can be calculated by the use of Poisson statistics, assuming random errors and systematic errors are separately accounted for, and that there is a background response.
4. For these calculations, two types of statistical counting errors must be considered quantitatively in order to define acceptable probabilities for each type of error:
  - a. Type I
    - 1) occurs when a detector response is considered above background when in fact it is not
    - 2) associated with  $L_C$

Refer students to Figure 6 in Study Guide.

## b. Type II

- 1) occurs when a detector response is considered to be background when in fact it is greater than background
  - 2) associated with  $L_D$
5. If the two probabilities (areas labeled I and II in Figure 6) are assumed to be equal, and the background of the counting system is not well-known, then the critical detection level ( $L_C$ ) and the minimum significant activity level ( $L_D$ ) can be calculated.
  6. The two values would be derived using the equations  $L_C = k\sigma_B$  and  $L_D = k^2 + 2k\sigma_B$ , respectively.
  7. If 5% false positives (Type I error) and 5% false negatives (Type II error) are selected to be acceptable levels, i.e., 95% confidence level, then if for example  $k = 1.645$  and the two equations can be written as:

$$L_C = 1.645 \sqrt{\frac{R_B}{T_B} + \frac{R_B}{T_S}} \quad (\text{Eq.16})$$

- where:
- $L_C$  = Critical detection level
  - $L_D$  = a priori detection limit [minimum significant activity level]
  - $k$  = Poisson probability sum for I and II (assuming I and II probabilities are equal)
  - $R_B$  = background counts
  - $T$  = count time (sample and background)

8. The minimum significant activity level,  $L_D$ , is the a priori (before the fact) activity level that an instrument can be expected to detect 95% of the time.
  - a. In other words, it is the smallest amount of activity that can be detected at a 95% confidence level.
  - b. When stating the detection capability of an instrument, this value should be used.
9. The critical detection level,  $L_C$ , is the lower bound on the 95% detection interval defined for  $L_D$ , and is the level at which there is a 5% chance of calling a background value "greater than background."

- a. This value ( $L_C$ ) should be used when actually counting samples or making direct radiation measurements.
  - b. Any response above this level should be counted as positive and reported as valid data. This will ensure 95% detection capability for  $L_D$ .
10. If the sample count time ( $T_S$ ) is the same as the background count time ( $T_B$ ), then equations 16 and 17 can be simplified as follows:

$$L_C = 2.32\sqrt{\frac{R_B}{T}} \quad (\text{Eq.18})$$

$$L_D = 2.71 + 4.65\sqrt{\frac{R_B}{T}} \quad (\text{Eq.19})$$

11. Therefore, the full equations for  $L_C$  and  $L_D$  must be used for samples with count times differing from the background determination time (95% CL used).

These equations assume that the standard deviation of the sample planchet/carrier background during the sample count (the planchet/carrier assumed to be 0 activity) is equal to the standard deviation of the system background (determined using the background planchet/carrier).

12. The critical detection level,  $L_C$ , is used when reporting survey results.
- a. It is used to say that at a 95% confidence level, samples above this value are radioactive.
  - b. This presupposes, then, that 5% of the time clean samples will be considered radioactive.
13. The minimum significant activity level,  $L_D$ , [also referred to as the LLD (Lower Limit of Detection) in some texts] is calculated prior to counting samples.

- a. This value is used to determine minimum count times based on release limits and airborne radioactivity levels.
- b. In using this value we are saying that at a 95% CL, samples counted for at least the minimum count time calculated using the  $L_D$  that are positive will indeed be radioactive (above the  $L_C$ ). This presupposes, then, that 5% of the time samples considered clean will actually be radioactive.

Review Example 9 in Study Guide with students.

Objective 2.03.22

(Insert site specific information here.)

Objective 2.03.23

## J. Crosstalk

### 1. Discrimination

- a. Crosstalk is a phenomenon that occurs on proportional counting systems (such as a Tennelec) that employ electronic, pulse-height discrimination, thereby allowing the simultaneous analysis for alpha and beta-gamma activity.
- b. Discrimination is accomplished by establishing two thresholds, or windows, which can be set in accordance with the radiation energies of the isotopes of concern.
- c. Recall that the pulses generated by alpha radiation will be much larger than those generated by beta or gamma.
  - 1) This makes the discrimination between alpha and beta-gamma possible.
  - 2) Beta and gamma events are difficult to distinguish; hence, they are considered as one and the same type by such counting systems.
- d. In practice, the lower window is set such that electronic noise and ultra-low-energy photon events are filtered out.
- e. Any pulse generated whose size is greater than the setting for the lower window is considered an event, or a count.
- f. The upper window is then set such that any pulses which surpass the upper discriminator setting will be considered an alpha count.

Refer students to Figure 7 in Study Guide.



- g. For output purposes, the system routes each count to a series of channels which simply keep a total of the counts routed to them.
    - 1) Channel A is for alpha counts
    - 2) Channel B is beta-gamma counts
    - 3) Channel C is total counts. As a sample is being counted, all valid counts registered (i.e., those which surpass the lower discriminator setting) are routed to the C-channel.
  - h. In addition, if the count was considered an alpha count (i.e., it surpassed the upper discriminator setting) it is routed to the A-channel; else it is tallied in the B-channel.
  - i. In effect, what occurs is that the number of beta-gamma counts (Channel B) are determined by subtracting the number of alpha counts (Channel A) from the total counts (Channel C), or  $B = C - A$ .
2. Origin of Crosstalk
- a. Now that we understand the process involved, there is a dilemma that stems from the fact that events are identified by the system as either alpha or beta-gamma according to the size of the pulse generated inside the detector.
  - b. The system cannot really tell what type of radiation has generated the pulse.
  - c. Rather, the pulse is labeled as "alpha" or "beta-gamma" by comparing the size of the pulse to the discriminator setting. It is the setting of the discriminator that poses the dilemma.
  - d. Alpha particles entering the detector chamber generally are attenuated by the detector fill-gas because of their high LET, thereby producing a large pulse.
  - e. Low-energy beta particles and photons will also lose all their energy within the detector gas, but nevertheless produce a smaller pulse because of their lower energies.

- f. High energy beta particles can still retain some of their energy even after having produced a pulse while traversing the detector volume.
    - 1) Rather than leaving the detector, as would a photon, the beta is reflected off of the detector wall and reenters the volume of gas, causing ionizations and generating a second pulse.
    - 2) These two pulses can be so close together that the detector sees them as one large pulse.
    - 3) Because of the large pulse size it can surpass the upper discriminator setting and is, therefore, counted as an alpha, and not as a beta.
  - g. The result is that alpha activity can be reported for a sample when in fact there was little or no alpha present.
  - h. Conversely, if a true alpha-generated pulse is not large enough so as to exceed the upper discriminator, it would be counted as a beta-gamma event. This is crosstalk.
  - i. The solution is not a simple one. The setting of the upper discriminator depends on the radiations and energies of the sources and samples being analyzed.
    - 1) If high energy beta radiations are involved, a significant portion of them could be counted as alpha events if the setting is too low.
    - 2) If the setting is too high, lower-energy alpha events could be counted as beta-gamma.
  - j. Typically, the setting of the discriminator will usually be some "happy medium."
  - k. A discussion of how this can be dealt with is in order.
3. Calibration Sources and Crosstalk
- a. For calibrations of Tennelec counting systems, the manufacturer provides the following general recommendations for discriminator settings:

- b. First, using a Strontium-90 beta source, set the upper ( $\alpha$ ) discriminator such that there is 1% beta-to-alpha crosstalk.
- c. Then, using a Polonium-210 alpha source, set the  $\alpha+\beta$  discriminator such that there is less than 3% alpha-to-beta crosstalk.
- d. Energies of sources used to calibrate counting systems should be the same as, or as close as possible to, the energies of isotopes in the samples analyzed.
- e. Wherever possible they should be a pure emitter of the radiation of concern.
- f. For beta-gamma sources the most popular isotope in radiation protection is Sr-90.
  - 1) It has a relatively long half-life of 29.1 years, but emits betas of only 546 keV.
  - 2) However, Sr-90 decays to Yttrium-90, another beta emitter which has a short half-life of only 2.67 days and emits a 2.281 MeV beta.
  - 3) Y-90 decays to Zirconium-90m which emits a 2.186 Mev gamma almost instantaneously to become stable.
  - 4) The daughters reach equilibrium with the strontium parent within a number of hours after source assay.
  - 5) Hence, for every Sr beta emitted a Y beta is also emitted, thereby doubling the activity.
  - 6) These sources are often listed as Sr/Y-90 for obvious reasons.
  - 7) This makes Sr/Y-90 sources an excellent choice and are used by many sites for calibrations and performance testing.
- g. Po-210 is essentially a pure alpha emitter. This is primarily the reason why it is recommended for calibrations and performance testing.
  - 1) It yields a strong alpha, but it also has a short half-life. A comparison of some alpha emitters is given in Table 5.

Refer students to Table 5 in Study Guide.

(Insert site specific information here.)

Objective 2.03.24

K. Voltage Plateaus

Objective 2.03.25

1. Very simply put, a voltage plateau is a graph that indicates a detector's response to an isotope with variations of high voltage.
  - a. The x-axis represents the high voltage and the y-axis the response (i.e., counts).
  - b. The resulting curve gives an indication of detector quality, and can indicate problems with the counting gas should they be present.
  - c. The curve can also be used to determine the optimum operating high voltage for the system.
2. Most automatic low-background counting systems provide several different analysis modes. These modes count samples at certain pre-determined voltages.
3. Counting systems generally provide three analysis modes:
  - Alpha only
  - Alpha then Beta
  - Alpha and Beta (simultaneous)
4. There are usually two voltage settings used in conjunction with these analysis modes:
  - Alpha voltage (lower)
  - [Alpha plus] Beta voltage (higher)
5. Recall that in a proportional counter the amount of voltage determines the amount of gas multiplication.
6. Because of the high LET of alpha radiation, at a lower voltage, even though the gas amplification will be lower, alpha pulses will still surpass the lower discriminator and some will even pass the upper discriminator.
7. Because of the lower gas amplification beta-gamma pulses will not be large enough to be seen. Therefore, any counts reported for the sample will be alpha counts.

8. In the Alpha only mode, the sample is counted once, at the alpha voltage. Counts may appear in either the A or B channels.
  - a. Upon output, the A and B channels will be added together and placed in Channel A and, therefore, reported as alpha counts; the B channel will be cleared to zero, thereby resulting in no beta-gamma counts.
9. In the Alpha then Beta mode, the sample is counted twice.
  - a. The first count interval determines the alpha counts using the alpha voltage.
  - b. The second count is done at the beta voltage.
  - c. The determination of alpha and beta-gamma counts in this mode is based strictly on the operating characteristics of the detector at the different voltages.
  - d. For this reason, the A and B counts are summed during both counting intervals to attain the total counts.
  - e. The separation of alpha and beta-gamma counts is then calculated and reported according to the following formula:

$$\alpha = \frac{A_1 + B_1}{CF_\alpha} \quad (\text{Eq.20})$$

$$\beta = (A_2 - B_2) - \alpha$$

- where:  $\alpha$  = reported gross alpha counts  
 $\beta$  = reported gross beta-gamma counts  
 $A_1, B_1$  = accumulated channel counts respectively, 1st interval  
 $A_2, B_2$  = accumulated channel counts respectively, 2nd interval  
 $CF_\alpha$  = alpha correction factor (ratio of alpha efficiency at alpha voltage to efficiency at beta voltage)

10. In the Alpha and Beta (simultaneous) mode, the sample is counted once using the beta voltage.
  - a. Alpha events are reported in the A channel, while beta-gamma counts are reported in the B channel.
  - b. This is the mode used most often.
11. As can be seen, the setting of the two voltages will have a direct impact on the number of counts reported for a given sample.
12. The determination of what these voltage settings should be must be done such that the optimum performance of the detector is obtained for those voltage regions. This is the purpose of a plateau.

Objective 2.03.26

(Insert site specific information here. The information that follows may be used as applicable.)
13. In conjunction with initial system setup and calibration by the vendor, two voltages plateaus are performed--alpha voltage and beta voltage.
14. For P-10 gas the alpha plateau is started at about 400 volts and the beta plateau at about 900 volts.
15. Alpha and beta plateaus are defined by the isotope being used and not by the channel being used to accumulate the counts.
16. More appropriately, the gross counts are accumulated and plotted for each type of isotope.
17. Each time that a count is completed, the high voltage is incremented a specific amount, typically 25 to 50 volts, and another count is accumulated.
18. This is repeated until the end of the range is reached, typically about 1800 volts.
19. With the high voltage set at the starting point, few or no counts are observed because of insufficient ion production within the detector.
20. As the voltage is increased, a greater number of pulses are produced with sufficient amplitude to exceed the discriminator threshold, and are then accumulated in the counter.

21. There will be a high voltage setting where the increase in counts levels off (see Figure 8).
22. This area is the detector plateau. Further increases in high voltage result in little change in the overall count rate.
23. The plateau should remain flat for at least 200 volts using a Sr/Y-90 source, and this indicates the plateau length.
24. Between 1750 and 1850 volts the count rate will start to increase dramatically. This is the avalanche region, and the high voltage should not be increased any further.
25. The region where the counts level off is called the knee of the plateau.
26. The operating voltage is chosen by viewing the plateau curve and selecting a point 50 to 75 volts above the knee and where the slope per 100 volts is less than 2.5%. [If used, refer students to Beta voltage figure in student guide]
27. This ensures that minor changes in high voltage will have negligible effects on the sample count. Poor counting gas or separation of the methane and argon in P-10 can result in a very high slope of the plateau.
28. Upon initial system setup and calibration the vendor determines and sets the optimum operating voltages for the system. Thereafter, plateaus should be generated each time the counting gas is changed.

### III. SUMMARY

This unit addressed the measures used to minimize error, fundamentals of binomial statistics and application of these fundamentals in a nuclear counting environment.

### IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.

**Course Title:** Radiological Control Technician  
**Module Title:** Dosimetry  
**Module Number:** 2.04

**Objectives:**

- 2.04.01 Identify the DOE external exposure limits for general employees.
- 2.04.02 Identify the DOE limits established for the embryo/fetus of a declared pregnant female general employee.
- 2.04.03 Identify the administrative exposure control guidelines at your site, including those for the:
  - a. General Employee
  - b. Member of the Public/Minor
  - c. Incidents and emergencies
  - d. Embryo/Fetus
- 2.04.04 Identify the requirements for a female general employee who has notified her employer in writing that she is pregnant.
- 2.04.05 Determine the theory of operation of a thermoluminescent dosimeter (TLD).
- 2.04.06 Determine how a TLD reader measures the radiation dose from a TLD.
- 2.04.07 Identify the advantages and disadvantages of a TLD compared to a film badge.
- 2.04.08 Identify the types of beta-gamma TLDs used at your site.
- 2.04.09 Identify the types of neutron TLDs used at your site.
- 2.04.10 Determine the requirements for use of TLDs used at your site.
- 2.04.11 Determine the principle of operation, and the types used, for the personnel neutron dosimeters used at your site.
- 2.04.12 Determine the principle of operation of self-reading dosimetry (SRD) used at your site.
- 2.04.13 Determine the principle of operation, and guidelines for use, for the alarming dosimeters used at your site.
- 2.04.14 List the types of bioassay monitoring methods at your site.
- 2.04.15 List different uses of area monitoring dosimeters.



**References:**

1. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5<sup>th</sup> ed.; Pacific Radiation Corporation; 2008.
2. ANL-88-26 (1988) "Operational Health Physics Training"; Moe, Harold; Argonne National Laboratory, Chicago.
3. "DOE Radiological Control Standard"; U.S. Department of Energy, 2008.
4. 10 CFR Part 835 (2007) "Occupational Radiation Protection".

**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

This lesson will introduce the types of instruments used to measure external and internal radiation to people. Dosimetry is the quantitative assessment of radiation received by the human body. There are several types of dosimeters in use worldwide. This material is valuable to all radiological control personnel since dosimeters are the only direct method to measure and document personnel radiation exposure and ensure regulatory compliance with applicable limits.

## C. Overview of Lesson

1. Dosimetry terms
2. DOE limits
3. Site administrative guidelines
4. TLDs
5. Site dosimetry
6. Bioassay assessment methods

## D. Introduce Objectives

O.H.: Objectives

**II. LESSON OUTLINE**

## A. DOSIMETRY TERMS

Understanding the terminology used in discussing dosimetry and exposure to ionizing radiation is essential for RCTs to do their job.

Majority from 835.2

Refer to the definitions provided in the Study Guide and review terms with class.

1. Absorbed Dose (D)

2. Equivalent Dose ( $H_T$ )
3. Whole Body
4. Extremity
7. Committed Equivalent Dose ( $H_{T,50}$ )
8. Radiation Weighting Factor ( $w_R$ )
9. Committed Effective Dose ( $E_{50}$ )
10. Total Effective Dose (TED)
11. Annual Limit on Intake (ALI)
12. Derived Air Concentration (DAC)
13. Bioassay
14. In Vivo
15. In Vitro
16. Background
17. Declared Pregnant Worker

Explain that the terms were revised in the 2007 amendment to 10 CFR 835

#### B. DOE LIMITS

1. Limits are the legal maximum values stated in 10 CFR 835. To exceed these values is to violate the law. Programs must be in place to ensure that exposures to ionizing radiation are kept below these levels. To accomplish this Administrative Control Levels are selected well below the regulatory limits. These control levels are usually multi-tiered with increasing levels of authority required to approve higher Administrative Control Levels.
2. Annual dose limits are based on a calendar year (January 1st through December 31st). For assigning internal equivalent dose received from intakes (committed effective dose and committed equivalent dose), the total 50-year committed dose received is assigned to the time of the intake even though the actual dose is proportionally received over the 50-year period.
3. See Table 3 for dosimetric equivalencies for circumstances when an individual conducts multiple activities involving both activities under 10 CFR 835.1(b)(1) and excluded activities, e.g., activities involving NRC licensed activities.

Objective 2.04.01

See Table 2

See Table 3

- |   |  |
|---|--|
| <ul style="list-style-type: none"> <li>a. General Employees</li> <li style="padding-left: 20px;">1) Whole body (internal + external) - 5 rems (0.05 sievert)</li> <li style="padding-left: 20px;">2) Lens of the eye - 15 rems (0.15 sievert)</li> <li style="padding-left: 20px;">3) Extremities - 50 rems (0.5 sievert)</li> <li style="padding-left: 20px;">4) Organ or tissue and skin - 50 rems (0.5 sievert)</li> <li>b. Minors/Public - 0.1 rem (0.001 sievert)</li> <li>c. Embryo/Fetus of Declared Pregnant Workers - 0.5 rems (0.005 sievert) per gestation period</li> <li>d. Emergency Exposures</li> <li>e. Planned Special Exposures</li> </ul> | <p>10 CFR 835.202</p> <p>10 CFR 835.207 &amp; .208</p> <p>10 CFR 835.206<br/>Objective 2.04.02</p> <p>DOE G 151.1-4,<br/>Chapter 7</p> |
| <p>C. SITE ADMINISTRATIVE GUIDELINES</p>  |  |
| <ul style="list-style-type: none"> <li>1. Radiological Workers</li> <li style="padding-left: 20px;"><i>(Insert site specific information here)</i></li> <li>2. Non-Radiation Worker</li> <li style="padding-left: 20px;"><i>(Insert site specific information here)</i></li> <li>3. Exposure from Incidents or Emergencies</li> <li style="padding-left: 20px;"><i>(Insert site specific information here)</i></li> <li>4. Embryo/fetus</li> <li style="padding-left: 20px;"><i>(Insert site specific information here)</i></li> </ul>  | <p>10 CFR 835.204</p> <p>Objective 2.04.03.a</p> <p>Objective 2.04.03.b</p> <p>Objective 2.04.03.c</p> <p>Objective 2.04.03.d</p>      |
| <p>D. TYPES OF DOSIMETRY</p>  |  |
| <ul style="list-style-type: none"> <li>1. As a result of irradiation, some solid substances undergo changes in some of their physical properties.</li> <li>2. These changes amount to storage of the energy from the radiation.</li> <li>3. Since the energy is stored, these materials can be used for dosimeters. The features that have been studied include:</li> </ul>   |  |

- a. Optical density changes
  - 1) Optical density changes involve a change in the color of some types of plastics and glass.
  - 2) In glass, the dose range is  $10^3$  to  $10^6$  rads (10 to  $10^4$  gray). The range for plastics is  $10^6$  to  $10^9$  rads ( $10^4$  to  $10^7$  gray).
  - 3) An example, film badges, provides low range, 10 mR to 10 R, for personnel and high range, 1 R to 1,000 R for accident readings.
- b. Thermoluminescence
  - 1) Thermoluminescence (TL) is the ability of some materials to convert the energy from radiation to a radiation of a different wavelength, normally in the visible light range.
  - 2) There are two categories of thermoluminescence.
    - a) Fluorescence - This is emission of light during or immediately after irradiation (within fractions of a second) of the phosphor. This is not a particularly useful reaction for TLD use.
    - b) Phosphorescence - This is the emission of light after the irradiation period. The delay time can be from a few seconds to weeks or months. This is the principle of operation used for thermoluminescent dosimeters.
  - 3) The property of thermoluminescence of some materials is the main method used for personnel dosimeters at DOE facilities and will be discussed in further detail.

Example - TV or computer monitor screen

#### E. TLD OPERATION

1. TLD's use phosphorescence as their means of detection of radiation.
2. Electrons in some solids can exist in two energy states, called the valence band and the conduction band. The difference between the two bands is called the band gap.
3. Electrons in the conduction band or in the band gap have more energy than the valence band electrons.

Objective 2.04.05

4. Normally in a solid, no electrons exist in energy states contained in the band gap. This is a "forbidden region." See figure 1 - "Electron Entrapment"
  5. In some materials, or if impurities are added, defects in the material exist or are made that can trap electrons in the band gap and hold them there. These trapped electrons represent stored energy for the time that the electrons are held. This energy is given up if the electron returns to the valence band.
  6. In most materials, this energy is given up as heat in the surrounding material, however, in some materials a portion of energy is emitted as light photons. This property is called luminescence. See figure 2 - "Thermoluminescence"
- F. TLD Reader Objective 2.04.06
1. Basic principle of operation
    - a. Heating of the TL material causes the trapped electrons to return to the valence band. When this happens, energy is emitted in the form of visible light.
    - b. The light output is detected and measured by a photomultiplier tube and a dose is then calculated.
    - c. A typical basic TLD reader contains the following components:
      - 1) Heater
      - 2) Photomultiplier tube
      - 3) Meter/recorderSee figure 3 - "TLD Reader"
  2. Glow curve
    - a. Obtained from heating process. See figure 4 - "Glow curve"
    - b. The light output from TL material is not easily interpreted. Multiple peaks result.
      - 1) As the material is heated, electrons trapped in "shallow" traps are released. This results in a peak as these traps are emptied. The light output drops off as these traps are depleted.

- 2) As heating continues, the electrons in deeper traps are released. This results in additional peaks. Usually the highest peak is used for calculations. The area under the curve represents the radiation energy deposited.
- c. After the readout is complete, the TLD is annealed at a high temperature. This process essentially zeroes the TL material by releasing all trapped electrons. The TLD is then ready for reuse.

#### G. ADVANTAGES AND DISADVANTAGES OF TLDs

Objective 2.04.07

1. Advantages (primarily as compared to film badges)
  - a. Able to measure a greater range of doses.
  - b. Doses may be easily obtained.
  - c. They can be read on site instead of being sent away for developing.
  - d. Quicker turnaround time for readout.
  - e. Reusable.
2. Disadvantages
  - a. Each dose cannot be read out more than once.
  - b. The readout process effectively "zeroes" the TLD.

#### H. SITE BETA/GAMMA TLDs

Objective 2.04.08

*(Insert site specific information here)*

#### I. SITE NEUTRON TLDs

Objective 2.04.09

*(Insert site specific information here)*

#### J. DOE EXTERNAL DOSIMETRY GENERAL PROVISIONS

10 CFR 835

1. Dosimetry shall be provided to and used by:
  - a. General employee expected equivalent dose to the whole body > 0.1 rem (0.001 sieverts); or > 10% of limits for extremities, organs, and other tissues.
  - b. Declared pregnant worker expected to receive 0.05 rem (0.0005 sievert) or more during the gestation period.

- c. Minors likely to receive 50% of Occupational Dose Limits or more in a year.
  - d. Public entering controlled areas likely to receive external equivalent dose to the whole body of 0.05 rem (0.0005 sievert) or more in one year.
  - e. Individuals entering a high or very high radiation area.
2. Neutron dosimetry provided when applicable threshold is likely to exceeded due to neutron radiation.
  3. Issued to individuals knowledgeable of proper use and worn only by assignee.
  4. Issuance of dosimeters should be discouraged for individuals other than those where there is a likelihood of being occupationally exposed to levels above monitoring thresholds.
  5. Dosimeters should be returned at required intervals. Individuals not returning dosimeters should be restricted.
  6. Primary dosimeters should be worn on the chest area or between the waist and the neck.
  7. Individuals should not be assigned multiple primary dosimeters during different periods of the dosimeter process year (exchange of primary dosimeter for multi-badging is acceptable); and avoid exposure of dosimeter to non-occupational sources.
  8. When dosimeters are lost, damaged, or contaminated, the individual should place work in a safe condition, exit and notify the RCO. Reenter only after review and approval.

#### K. SITE REQUIREMENTS FOR USE OF TLDs

*(Insert site specific information here)*

Objective 2.04.10

#### L. SITE PERSONNEL NEUTRON DOSIMETERS

*(Insert site specific information here)*

Objective 2.04.11

#### M. POCKET AND ELECTRONIC DOSIMETERS

1. Provide real time dose indication.
2. Shall be issued for entry into High or Very High Radiation Area.



3. Should be issue when planned activity levels exceed 0.05 rem (0.0005 sievert) or 10% of control levels.
4. Should be issued when required by RWP.
5. Worn with primary dosimetry and located on chest area, on or between the waist and the neck.
6. Should be read periodically and should not exceed 75% of full scale.
7. Authorized work should cease when supplemental dosimeter indicates total dose or dose rate is > than expected.
8. When supplemental dosimeters differ by more than 50% from primary dosimeters and the primary result is >0.1 rem (0.001 sievert), an investigation should be initiated.

#### N. SITE SELF-READING DOSIMETERS

*(Insert site specific information here)*

Objective 2.04.12

1. Self Reading Pocket Dosimeters (SRPD)
  - a. Direct reading ion chamber.
  - b. Utilizes two electrodes:
    - 1) Fiber electrometer (fixed and moveable components)
    - 2) Metal frame
  - c. As chamber is ionized the charge is decreased on the movable and fixed fiber.
  - d. The movement of the fiber is proportional to the dose received.

See figure 5 - "SRPD"

Note: SRPDs with steel walls are usually insensitive to beta and low energy gamma

See figure 6 -"SRPD Reading"

#### O. SITE ALARMING DOSIMETRY

*(Insert site specific information here)*

Objective 2.04.13

#### P. INTERNAL DOSIMETRY REQUIREMENTS

Re-enforce difference between "internal" and "external" dose

1. Internal dose evaluation programs shall be conducted for: 10 CFR 835.402
  - a. General employees - likely to receive 0.1 rem (0.001 sievert) or more committed effective dose.
  - b. Declared pregnant workers - likely to receive an intake resulting in an equivalent dose of 10% of the limit (or 0.05 rem [0.0005 sievert]).
  - c. Minors - likely to receive a committed effective dose in excess of 50% of limit (or 0.05 rem [0.0005 sievert]).
  - d. Public - likely to receive a committed effective dose in excess of 50% of limit (or 0.05 rem [0.0005 sievert]).
2. Estimation shall be based on bioassay results rather than air concentration values unless air concentration values are more reliable or bioassay results are unavailable.
3. Follow-up bioassay monitoring is typically required when results indicate a committed effective dose of 0.1 rem (0.001 sievert) or more.
4. A bioassay program should be considered for personnel routinely exposed to surface or airborne contamination or to radionuclides readily absorbed through the skin.
5. Personnel are required to submit bioassay samples.
6. Personnel shall be notified of positive bioassay results.

#### Q. BIOASSAY ASSESSMENT METHODS

1. General
  - a. Today's technology has not produced a device that allows accurate determination of internal exposure following the entry of radioactive materials into the body.
  - b. The method that is used to determine internal dose contributions relies on calculation of dose to affected portions of the body based on the quantities of radioactive materials in the body. Thus, the real problem becomes one of quantifying the amount of material present.
  - c. Bioassay is the term that is used to describe the assessment of the quantity of radioactive material present in the body. There are currently two types of bioassay measurements employed in nuclear industries:

- 1) In vivo - analysis of living tissue.
- 2) In vitro - analysis of excreted samples.
- d. Bioassay programs are designed to fulfill two needs:
  - 1) Evaluate effectiveness of contamination control practices.
    - a) Routine bioassay programs utilize submission and analysis of samples from workers in facilities where the likelihood of intake exists.
    - b) Primarily limited to urinalysis due to ease of sample collection.
    - c) Also includes initial, routine, and termination whole body counts.
  - 2) Evaluate potential consequences of accidental inhalation or ingestion of large quantities of radioactive materials.
    - a) Can involve all types of bioassay measurements with collection and analysis of nasal, urine, and fecal samples.
    - b) Whole body counts provide immediate indications for given radionuclides if individual(s) involved are free of external contamination.
2. In vivo measurements
  - a. The amount of materials is estimated by counting radiation emitted by radioactive materials in the body.
  - b. Only good for radioactive materials which emit gamma radiation of sufficient abundance and energy to be detected and statistically measured.
  - c. With use of expensive, sophisticated spectroscopy, most contributors (radionuclides present) can be identified.
  - d. Site In vivo methods

*(Insert site specific information here)*
  - e. Advantages

Objective 2.04.14

- 1) No sample required.
  - 2) Results obtained quickly.
  - 3) Some equipment design allows field use.
  - 4) Time and manpower requirements minimized.
- f. Disadvantages
- 1) Limited to detection and measurement of gamma emitters.
  - 2) Individual must be free of external contamination.
  - 3) Long count times for identification.
  - 4) Effects of background.
  - 5) Complex calibration procedure and calibration equipment.
  - 6) Expense.
  - 7) Quantification error due to differences in tissue structure from one person to another as compared to calibration phantom.
3. In Vitro Measurements
- a. The amount of material present in the body is estimated using the amount of materials present in excretions or secretions from the body.
  - b. Samples include urine, feces, blood, sputum, saliva, hair and nasal discharges.
  - c. Calculation requires knowledge of and use of metabolic models which allow use of activity in samples to be related to activity present in the body.
  - d. Resulting dose calculations to quantify committed and effective doses are estimates.
    - 1) This is due partly to use of default values for measurements that cannot be readily made such as mass of particular organs, volumes of particular fluids, etc., in lieu of actual values for individual involved. Remember that reference man is an average.

- 2) Another contributing factor is different metabolism from one individual to another.

e. Types of analysis

- 1) Urinalysis - indicates intake of primarily soluble material.
- 2) Fecal analysis - primarily indicates intake of insoluble material. Provides relatively rapid indication.
- 3) Sputum - may contain insoluble material initially deposited in the lung and later eliminated by ciliary action.
- 4) Saliva - may be use to estimate uptake of tritium oxide.
- 5) Nasal discharge - indication of the deposition of the coarsest inhaled particles in the nose.

f. Site in vitro methods

*(Insert site specific information here)*

Objective 2.04.14

g. Advantages of in vitro measurements

- 1) Can be used for estimation of neutron doses using activation product concentration in hair and blood ( $^{32}\text{P}$  and  $^{24}\text{Na}$ ).
- 2) Can be used to quantify presence of materials which decay by alpha and beta emission to allow detection and measurement with external detector systems.

h. Disadvantages

- 1) Requires sample submission and analysis.
- 2) Time and manpower requirements.

3. Bioassay Scheduling Program

- a. Contamination found at a given site will depend on the materials that are used and produced at the site. Thus, the materials that internal dosimetrists are primarily concerned with will change from one site to another as well.

- b. Baseline/Routine/Exit Evaluations  
*(Insert site specific information here)*
- c. Special Evaluations  
*(Insert site specific information here)*
- d. Investigation Levels  
*(Insert site specific information here)*
- e. Medical Uses  
*(Insert site specific information here)*

#### R. AREA MONITORING DOSIMETERS

Objective 2.04.15

1. Area monitoring dosimeters are often used to record and document radiation levels in routinely occupied areas adjacent to areas where radiation or radiological operations exist.

Note: This type of monitoring does not apply when the radiation hazard of concern arises from low-energy beta sources (e.g.,  $^{14}\text{C}$ ,  $^3\text{H}$ ).

2. Establishment and maintenance of a comprehensive area monitoring program can demonstrate that doses outside Radiological Buffer Areas are negligible, and help to minimize the number of areas requiring the issuance/use of personnel dosimeters.

Minimizing the number of personnel dosimeters issued saves in the costs of operating the dosimetry program and reduces costs associated with maintaining personnel with enhanced training and qualifications.

3. Area monitoring dosimeters are also used to help characterize workplace conditions to verify the effectiveness of physical design features, engineering controls, and administrative controls. In addition, area monitoring dosimeter results can be used to support dosimetry investigations where personnel express concerns about their work environments and exposure to ionizing radiation.
4. Finally, area (and equipment) monitoring dosimeters are useful for the determination of dose rates and/or integrated doses for:

- a. equipment and/or areas with suspected high dose rates;
- b. devices emitting pulsed radiation not accurately measured with portable survey instruments;
- c. highly collimated beams of radiation; and
- d. radiological incidents.

### **III. SUMMARY**

#### A. Review major topics

1. Dosimetry terms
2. DOE limits
3. Site administrative guidelines
4. TLDs
5. Site dosimetry
6. Bioassay assessment methods

#### B. Review learning objectives

### **IV. EVALUATION**

Evaluation shall consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% shall be the minimum passing criteria for examinations.

**Course Title:** Radiological Control Technician  
**Module Title:** Contamination Control  
**Module Number:** 2.05

**Objectives:**

- 2.05.01 Define the terms "removable and fixed surface contamination," state the difference between them and list common methods used to measure each.
- 2.05.02 State the components of a radiological monitoring program for contamination control and common methods used to accomplish them.
- 2.05.03 State the basic goal of a contamination control program and list actions that contribute to its success.
- 2.05.04 State the basic principles of contamination control and list examples of implementation methods.
- 2.05.05 List and describe the possible engineering control methods used for contamination control.
- 2.05.06 State the purpose of using protective clothing in contamination areas.
- 2.05.07 List the basic factors which determine protective clothing requirements for personnel protection.

**References:**

- 1. "DOE Radiological Control Standard"; U.S. Department of Energy, 2008.
- 2. "The Health Physics and Radiological Health Handbook," Shleien; 1992.
- 3. 10 CFR Part 835 (2007) "Occupational Radiation Protection".

**Instructional Aids:**

- 1. Overheads
- 2. Overhead projector/screen
- 3. Chalkboard/whiteboard
- 4. Lessons learned



**I. MODULE INTRODUCTION**

## A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

Contamination control is probably one of the most difficult and challenging tasks the Radiological Control Technician will encounter.

## C. Overview of Lesson

1. Types of Contamination
2. Assessing Contamination Hazards
3. Basic Goal of Contamination Control
4. Contamination Control Measures
5. Basis for Establishing Protective Clothing Requirements

## D. Introduce Objectives

O.H.: Objectives

**II. MODULE OUTLINE**

## A. TYPES OF CONTAMINATION

Objective 2.05.01

Contamination is simply defined as radioactive material in an unwanted location, e.g., personnel work areas, etc. Two types are possible:

1. Fixed Contamination - Radioactive surface contamination that is not easily transferred to other personnel or equipment through normal contact.
2. Removable Contamination - Radioactive surface contamination that is easily transferred to other personnel or equipment through normal contact.

3. Removable contamination is measured by a transfer test using a suitable sampling material. Common materials used for the monitoring are the standard paper disk smear or cloth smear. The standard technique involves wiping approximately  $100\text{ cm}^2$  of the surface of interest using moderate pressure. A common sampling practice used to ensure a  $100\text{ cm}^2$  sample is to wipe a 16 square inch "S" shape on the surface (i.e., four inches by four inches). Qualitative, large area wipe surveys may be taken using other materials, such as Masslin cloth or Kimwipe, to indicate the presence of removable contamination. These are commonly used when exact levels of contamination are not required.
4. Fixed contamination is measured by use of a direct survey technique. This technique, commonly referred to as "frisking," indicates the total contamination on a surface apparent to the detector from both fixed and removable. To evaluate the fixed component the removable level must be subtracted from the total, when non-removable levels are to be recorded.

Appendix D to 10 CFR 835 lists contamination levels in units of  $\text{dpm}/100\text{ cm}^2$ . Typical evaluation of fixed contamination monitoring includes adjusting the portable instrument count rate (counts per minute) to account for the area of the monitoring instrument (probe area) and the instrument efficiency to obtain units of  $\text{dpm}/100\text{ cm}^2$ .

Footnote 4 to Appendix D states that when "removable contamination on objects of surface area less than  $100\text{ cm}^2$  is determined, the activity per unit area shall be based on the actual area and the entire surface shall be wiped". For example, for an object with a total surface area of  $50\text{ cm}^2$ , the entire object would be wiped and the count result would be divided by the counting efficiency and multiplied by an area adjustment factor of two ( $100\text{ cm}^2/50\text{ cm}^2$ ) to get a result in units of  $\text{dpm}/100\text{ cm}^2$ . A similar approach may be used for fixed contamination monitoring of objects with surface area less than  $100\text{ cm}^2$ . However, care must be taken in monitoring very small objects and the sensitivity of the monitoring protocol should be evaluated.

## B. ASSESSING CONTAMINATION HAZARDS

In order to acquire the radiological information necessary for contamination control, the presence of contamination must be identified. In order to achieve this, a radiological monitoring program must be applied. The components are:

Objective 2.05.02

- Constant monitoring
  - Area and equipment surveys
  - External personnel surveys
  - Personnel internal monitoring and bioassay
1. Constant monitoring - There are various types of constant monitoring instruments installed throughout facilities to warn personnel of radiation and contamination hazards. Identify the types of instrumentation used in the constant monitoring.
    - a. Some instruments are permanently installed, and some instruments are portable to allow movement from place to place as deemed appropriate.
    - b. Continuous air monitor (CAM) - These instruments sample the air in specific locations continuously for radioactive contamination. Other methods of continuously monitoring for airborne contamination are also used.

- 1) Filter monitors draw air through a moving particulate filter, which is then monitored by a detector system.
  - 2) Direct monitors pull air flow through an internal detector to directly identify radioactive materials present.
  - 3) CAMs can give both a visual and audible alarm to warn personnel of the presence of airborne contamination.
- c. Process monitoring systems - These systems monitor certain operations in various facilities to alert operators of abnormal conditions which might lead to the release of excessive amounts of radioactivity to the facility or environment.
2. Area and equipment surveys - Surveys are conducted routinely throughout facilities to locate sources of radiation and contamination. Pre-job surveys are performed to evaluate hazards and determine work limitations and physical safeguards within locations identified.
- a. Direct instrument surveys
    - 1) Various types of portable survey instrumentation are used to measure the presence of radioactive contamination on a floor or surface.
    - 2) This is the only method available to detect "fixed" surface contamination.
  - b. Smear surveys
    - 1) A disk smear is wiped over an area of 100 square centimeters and counted with proper instrumentation to determine the activity of the nuclides present in units of dpm/100 cm<sup>2</sup>.
      - a) Disk smears are small so they are usually used in an area of suspected contamination.
      - b) Experience will dictate to the surveyor where contamination is most likely to occur and hence those areas that should be surveyed with disk smears.

- 2) Many routine contamination surveys are taken with a chemically treated cloth called a masslinn.
  - a) Cloth is lightly pushed over a specified area and scanned with an appropriate detector to detect the presence of contamination.
  - b) If contamination is detected, a more thorough disk smear survey should be performed.
  - c) Large area wipes are used only as an **indication** of removable surface contamination.
  - d) Disk smears are required if contamination levels are to be quantified.
  
3. External Personnel Surveys - Personnel surveys are either performed by the individual (self-monitoring) using hand-held or automated instruments or by a RCT. Monitoring by a RCT is usually conducted whenever contamination of the body or clothing is suspected, or as required by exit monitoring when self-monitoring is not allowed. The following describes the general types of hand-held or automated instruments that are commercially available.
  - a. Personnel monitors - Sensitive hand held detectors used by personnel to identify contamination on themselves whenever contamination is suspected.
    - 1) Portable Geiger-Mueller (GM) or scintillation detectors that are installed at strategic locations throughout the facilities.
    - 2) These monitors are used whenever exiting contaminated areas or RBAs.
  
  - b. PCMs (Personnel Contamination Monitors) provide personnel with an external whole body monitoring system.
    - 1) PCMs are typically located at the RBA exits in facilities with a high occupancy factor.
    - 2) Contamination detectors within the monitors are capable of performing a survey of the whole body in a period of a few seconds, dependent upon background radiation levels and the personnel contamination limit of concern.

- 3) These systems provide a more reliable method of locating personnel contamination over hand-held instruments.
- c. Portal monitors - Portal monitors are "door frame" type devices which provide a final monitoring point to ensure contamination is not spread outside the facility to other facilities or the general public.

Personnel are required to use (pause and walk through) this type of monitoring system prior to exiting specified areas.

- d. Personnel surveys - These are performed by RCTs whenever contamination of clothing or the body is suspected, or as required when friskers or automated instruments are not available.
  - 1) The whole body should be surveyed with special attention given to areas which are more likely to become contaminated.
  - 2) A minimum survey of the hands, arms, and front portions of the body must be performed upon completion of work or prior to leaving the area for glovebox, laboratory fume hood, sample station, or localized benchtop operations.
  - 3) Contamination of the feet (shoes) would indicate removable surface contamination on the floor just traversed.
  - 4) The nose and mouth should be surveyed upon discovery of facial contamination or if airborne contamination was detected in the work area to determine if bioassay sampling is required.
  - 5) The nose can be swabbed with Q-tips and the swab counted in a smear counter.
  - 6) Contamination of the nose or mouth may indicate airborne contamination.
  - 7) All open wounds must be monitored since contaminants can be readily absorbed into the body.
  - 8) Upon detecting personnel contamination, follow-up area and/or equipment surveys may be necessary to determine the source of contamination and the extent the contamination has spread, if any.

4. **Personnel internal monitoring** - A routine program of internal contamination monitoring is conducted as a final check on contamination control procedures.  
Typical programs consist of external whole/partial body counting and/or urinalysis.
  - a. **In-vivo bioassay (whole/partial body counting)** - Individual is placed inside an array of very sensitive detectors to measure the activity and energies of gamma ray emissions from inside the body.  
Information can be used to determine the amount and identify the type of nuclides present.
  - b. **In- vitro bioassays** - Performed by collection of urine or feces samples from an individual to determine type and activity of the nuclides present in bodily waste.
    - 1) Information is used to approximate the amount of nuclides present in the body by their calculated rate of elimination.
    - 2) Can be used to assess the presence of non-gamma emitting nuclides.

#### C. BASIC GOAL OF CONTAMINATION CONTROL

Objective 2.05.03

Once the presence of radioactive material has been located, the basic goal underlying any effective contamination control program is to minimize contaminated areas and maintain contamination levels as low as reasonably achievable.

1. If the presence of removable contamination is discovered, decontamination is a valuable means of control.
  - a. In some situations, this is not always possible.
    - 1) **Economical conditions:** Cost of time and labor to decontaminate a location out- weighs the hazards of the contamination present.
    - 2) **Radiological conditions:** Radiation dose rates or other radiological conditions present hazards which far exceed the benefits of decontamination.
    - 3) **Operating conditions:** Some areas, e.g., hot cells, will be contaminated due to normal operations.
  - b. Other means of control, such as engineering controls, administrative procedures, or personnel protective equipment, must be initiated when decontamination is not possible.

2. "Good Housekeeping" is a prime factor in an effective contamination control program. It involves the interactions of all groups within the facility. Each individual must be dedicated to keeping "his house clean" to control the spread of contamination.

Every possible effort should be made in all operations to confine the spread of radioactive materials to the smallest possible area.

3. A sound preventive maintenance program can prevent many radioactive material releases.
4. All material taken into or out of contaminated areas should be controlled.
5. Regardless of the precautions taken, radioactive materials will occasionally escape and contaminate an area.
6. Radiological Control Technicians should always be alert for potential violations to the basic principle of contamination control.
  - a. Use of improper contamination control methods
  - b. Bad work practices
  - c. Basic rule or procedure violations
  - d. Radioactive material releases or liquid spills
7. Radiological Control Technicians should always ensure that the proper procedures to avoid the spread of contamination are followed or implemented.

#### D. CONTAMINATION CONTROL MEASURES

Objective 2.05.04

Controlling the spread of contamination is probably the most difficult and challenging task the Radiological Control Technician will encounter. The basic principles of contamination control are:

Objective 2.05.05

- Access/Administrative Controls
- Engineering Controls
- Personnel Protective Measures
- Decontamination
- Preventive Methods

1. Access/Administrative Control



Once the location of contamination has been identified and quantified and radiological areas have been established, we must adequately control access to these areas.

Boundaries of radiological areas must be clearly marked. This is accomplished by using radiological postings and tags identifying entrances into these areas to restrict access.

Two basic access control points are used in contamination control.

- a. The **primary access** control point in a facility is the **entry and exit portal between the clean area and the radiologically controlled area or RBA**. The success of a control program is based on controlling the movement of personnel and equipment between these areas to prevent release of contamination to a clean location.
  - b. **Secondary access** control points (perhaps the most important) are set up within the RBAs to control access between surface contamination areas and non-contaminated areas. Yellow and magenta rope, tape, chain, or similar barriers are used to identify boundaries. Step-off-pads provide a recognizable demarcation to personnel between the contaminated area and the RBA.
    - 1) Special requirements will always be established for entry and exit through these access control points.
    - 2) When radiological conditions are severe, the access control point will be continuously manned by Radiological Control Technician.
    - 3) Proper procedures must be established and observed for crossing the SOP to prevent spread of contamination out of the area.
    - 4) All tools and/or equipment used in contaminated areas which are unmonitored shall be placed in plastic bags or securely wrapped in plastic before being removed from the area.
    - 5) All personnel and materials exiting the area shall be monitored to ensure they are free of contamination.
2. Engineering Controls - There are several specific methods of engineering control which can be utilized.

- a. Ventilation - The design of permanent or temporary ventilation systems needs to be such that air flow is from clean areas to RBAs, to areas of moderate contamination, to areas of high contamination, and finally to a exhaust system capable of removing any contamination from the air. Slight negative pressure is typically maintained in buildings/rooms where potential contamination exists.
- b. Containment - On jobs with very high contamination potential, a plastic tent, (greenhouse or hut) can be built around the work area to confine all contamination to as small an area as possible.
- 1) A portable ventilation exhaust system (such as HEPA's) may be used to control air flow in the containment hut and remove airborne contamination.
  - 2) Where possible, small containment devices, such as glove boxes, glove bags, or hoods can be used to contain the contamination depending on the nature and location of the work being performed.
  - 3) Contaminated tools or equipment are placed in plastic bags, or securely wrapped in plastic, before being moved outside a contaminated area.
  - 4) When possible, wrapping tools or equipment prior to entry can help control contamination during use inside the contaminated area.
- c. Design and Control - Design of facilities should be such that efficiency of maintenance, operations, and decontamination is maximized.
- 1) Components should be selected that minimizes the buildup of radioactivity.
  - 2) Support facilities should be included that provide for the donning and doffing of protective clothing and for personnel monitoring.
  - 3) Personnel traffic should be routed away from contaminated areas.
3. Personnel Protective Measures - If engineering methods are not adequate, then personnel protective measures, such as protective clothing and respiratory equipment, will be used.

Objective 2.05.06

- a. The purpose of protective clothing is to keep contamination off the skin and clothing of the workers.
    - 1) Protective clothing allows personnel to work inside a contaminated area with removable contamination and to exit the area without spreading contamination to uncontrolled areas.
    - 2) Use of protective clothing alone will not guarantee complete elimination of personnel contamination and is not a substitute for implementing proper controls, but if used properly, protective clothing will afford a high degree of protection.
    - 3) All personnel entering contaminated areas with removable contamination will be required to wear certain items of protective clothing.
    - 4) Types of clothing required will vary depending upon the contamination levels and the nature of the work to be performed.
  - b. Some type of respiratory protective equipment will be required for work in areas where very high contamination levels exist or airborne contamination is present.
3. Decontamination - Line management is responsible for ensuring prompt decontamination, where practical, of facilities, tools, equipment, and material so that contamination can be minimized in the workplace.

Reasonable efforts should be directed toward the decontamination and unconditional release of these items rather than their disposal as radioactive waste.

4. Preventive Methods - The following are practical methods used for the prevention/control of contamination.
- a. Identify and repair leaks before they become a serious problem.
  - b. Establish adequate work controls before starting jobs.
  - c. While conducting pre-job briefs, discuss measures that will help reduce or prevent contamination spread.
  - d. Change out gloves or protective gear as necessary to prevent cross-contamination of equipment.

- e. Pre-stage areas to prevent contamination spread from work activities.
- f. Cover piping/equipment below a work area to prevent dripping contamination onto less contaminated areas.
- g. Cover/tape tools or equipment used during the job to minimize decontamination after the job.
- h. Follow good work practices such as good housekeeping and cleaning up after jobs.
- i. Confine the spread of radioactive material releases by a sound preventive maintenance program.
- j. Control and minimize all material taken into or out of contaminated areas.

E. BASIS FOR ESTABLISHING PROTECTIVE CLOTHING REQUIREMENTS

Objective 2.05.07

1. The basic factors that determine the type and extent of protective clothing required are:
  - a. type and form of contamination
  - b. levels of contamination
  - c. type of work being performed
  - d. potential for increased levels of contamination
  - e. the area of the body at risk
  - f. competing hazards, i.e., asbestos, heat stress, etc.
2. Once the types of protection needed are established, the most efficient protective clothing must be selected from the different articles of protective clothing available for use.
  - a. Whole body protection
    - 1) Laboratory coat
      - a) Provides protection from low levels of contamination.
      - b) Only applicable when the potential for body contact with contaminated surfaces is very low.

- c) Lab Coats are generally worn for hands-off tours and inspections in areas with removable contamination at levels 1 to 10 times the values in Table 2-2 of the Radiological Control Standard.
  - d) Lab coats may also be worn during benchtop, laboratory fume hood, sample station, and glovebox operations.
- 2) Coveralls
- a) Provides protection from low to moderate levels of **DRY** contamination.
  - b) Protection is low when body contact with contaminated surfaces is prolonged (since contamination can be ground into the cloth).
  - c) Protection is low when the surface is wet.
  - d) Degree of protection can be increased by use of more than one pair at a time to protect the body.
  - e) Not effective against radionuclides with high permeation properties (gases, tritium, etc.).
- 3) Plastic coveralls
- a) Provides protection from high levels of dry contamination.
  - b) Provides protection from wet forms of contamination.
  - c) Provides limited protection from tritium and other highly permeating radionuclides being transported through the coveralls to the skin surface.
- 4) Disposable coveralls
- a) Used for work involving mixed hazards, i.e., asbestos, PCBs, etc., where reuse is not desirable.
  - b) Types of suits are tyvek, gortex, etc. which provide moderate protection from radioactive contamination.

- c) Disposable coveralls can be easily torn.
- b. Hand protection
  - 1) Surgical gloves
    - a) Minimal requirement
    - b) Normally used in only light contamination work areas
    - c) High degree of dexterity
    - d) Fairly easily torn or punctured
  - 2) Rubber gloves
    - a) Lightweight
    - b) Provides good gripping surface
    - c) Normally used in moderate to heavy contamination locations
    - d) Greater puncture, abrasion and solvent resistance, but afford a lower degree of dexterity than surgical gloves.
  - 3) Neoprene gloves
    - a) Synthetic rubber gloves mounted to various containment devices to allow access by the wearer into the device.
    - b) Used to provide protection for the wearer when working inside a containment device in which highly contaminated materials are present.
    - c) Usually of arm length attached to dry boxes, glove boxes and bags, or other cabinets.
    - d) Provides a gas tight seal to the structure.
    - e) Gloves are normally taped to the sleeve of the lab coat, coveralls, plastic suit, etc. and are tabbed to permit easy removal.
  - 4) Cotton glove liners

May be worn inside standard gloves for comfort, but should not be worn alone or considered as a layer of protection.

5) Leather or canvas work gloves

Should be worn in lieu of or in addition to standard gloves for work activities requiring additional strength or abrasion resistance.

c. Foot protection

1) Booties: Used to protect lower leg area below coveralls from contamination. Different constructions used:

a) Plastic

b) Cloth (sometimes called cloth shoe covers)

2) Shoe covers: Worn over booties to provide a second layer of protection and provide traction to wearer.

Normally are constructed of plastic or rubber.

3. Respiratory protection

a. Full-face masks: Used to filter particulate radionuclides and/or radioactive Iodine from the breathing air of the wearer when the surrounding atmosphere is not immediately dangerous to the life and health of the wearer.

b. Supplied air systems: Used to prevent inhalation of particulate and gaseous radionuclides by the wearer in a non-life threatening atmosphere.

c. Self-contained breathing apparatus (SCBA): Used to provide a portable source of breathing air to the user when entering an atmosphere which may be immediately dangerous to life and health.

d. Medical approval, training, and fit testing are required prior to respiratory protection use.

1) Systems should be in place to verify these criteria in the field.

2) The wearer should be clean shaven in the area of fit.

- 3.) The wearer should perform fit checks of their respirators to ensure a proper seal.
4. Facility Protective Clothing Requirements  
(Insert facility specific material here)

### III. SUMMARY

- A. Review major topics
  1. Types of Contamination
  2. Assessing Contamination Hazards
  3. Basic Goal of Contamination Control
  4. Contamination Control Measures
  5. Basis for Establishing Protective Clothing Requirements
- B. Review learning objectives

### IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.



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**Course Title:** Radiological Control Technician  
**Module Title:** Air Sampling Program/Methods  
**Module Number:** 2.06

**Objectives:**

- 2.06.01 State the primary objectives of an air monitoring program.
- 2.06.02 Describe the three physical states of airborne radioactive contaminants.
- 2.06.03 List and describe the primary considerations to ensure a representative air sample is obtained.
- 2.06.04 Define the term "isokinetic sampling" as associated with airborne radioactivity sampling.
- 2.06.05 Identify the six general methods for obtaining samples or measurements of airborne radioactivity concentrations and describe the principle of operation for each method.
- Filtration
  - Volumetric
  - Impaction/impingement
  - Adsorption
  - Condensation/dehumidification
  - In-line/flow-through detection
- 2.06.06 Describe the general considerations for selection of an air monitoring method.
- 2.06.07 State the purpose of the five primary types of airborne radioactivity samplers/monitors:
- Personal air samplers (breathing zone)
  - High volume/flow rate air samplers
  - Low volume/flow rate air samplers
  - Portable continuous air monitors
  - Installed continuous air monitoring systems
- 2.06.08 List the factors that affect the accuracy of airborne radioactivity measurements and describe how these factors affect sample accuracy.
- 2.06.09 Describe the site air monitoring program that includes monitoring frequencies, calculational methods, applicable derived air concentration limits, and methods for determining radon interference.

**References:**

1. "Introduction to Health Physics"; Cember, Herman; 4nd ed.; McGraw-Hill Medical; 2008.
2. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5<sup>th</sup> ed.; Pacific Radiation Corporation; 2008.
3. Moe Harold, Operational Health Physics Training, ANL-88-26, Department of Energy, Argonne National Laboratory, Chicago, 1988.
4. "Air Monitoring", Chapter 10 of Implementation Guide for Use with 10 CFR 835, "Occupational Radiation Protection".

**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

Before the proper internal exposure control methods can be determined for personnel, an estimate of the airborne radioactivity concentration must be obtained. Additionally, airborne radioactivity measurements are necessary to ensure that the control measures assigned are effective and continue to be effective.

## C. Overview of Lesson

1. Purpose and objectives of airborne radioactivity sampling
2. The nature of airborne radioactivity
3. Representative air samples
4. Basic sampling methods
5. Selection of the air sampling method
6. Primary types of air samplers
7. Basic air sample calculations

## D. Introduce Objectives

O.H.: Objectives

**II. MODULE OUTLINE**

## A. PURPOSE AND OBJECTIVES OF AIRBORNE RADIOACTIVITY SAMPLING

1. Airborne radioactive contaminants are of concern to the radiological control organization due to the biological effects of the ionizing radiation emitted by those contaminants.

2. Inhalation of radioactive airborne particles is one of the most important routes of entry of radionuclides into the human body.
3. This represents a relatively complicated process that depends on particle size distribution of the airborne particles, their dynamical behavior in air, and the physical and chemical properties of the particles after deposition in the respiratory tract.
4. Air monitoring is performed to identify and monitor airborne radioactive material in order to control the intake of airborne radioactive material by workers.
5. Regulations govern the allowable or limiting doses to an individual.
  - a. The total effective dose of an individual is determined by combining the external and internal effective dose values.
  - b. Typically, airborne radioactivity levels are maintained well below allowable levels to keep the internal dose contribution to the total effective dose small.
  - c. Confirmation that airborne radioactivity levels are maintained low is accomplished by the airborne radioactivity sampling program.
  - d. It is important to note that the individual equivalent dose from internal sources is **not** normally determined from air sampling analysis data, unless other information, such as bioassay data, is unavailable, inadequate, or internal dose estimates based on representative air concentration values are demonstrated to be as or more accurate.
6. It is necessary to be aware that the air monitoring program is only one element of a comprehensive radiation protection program.
  - a. Individuals involved with the air monitoring program should interact with personnel working in other elements of the radiation protection program, particularly with individuals involved in contamination control and internal dosimetry.

7. The primary objectives of an air monitoring program are: Objective 2.06.01
- a. To measure the concentration of the radioactive contaminant(s) in the air by collection and analysis
  - b. To identify the type and physical characteristics of the radioactive contaminant to help evaluate the hazard potential to the worker
  - c. To evaluate the performance of airborne radioactivity control measures
  - d. To assess air concentration data in order to determine if bioassay sampling should be initiated to verify whether an exposure has occurred, and if so, to determine the magnitude of the exposure.
8. Additionally, the air monitoring program must demonstrate that airborne radioactivity released to the general environment is maintained as low as reasonably achievable and below the allowable limits established by regulatory agencies.
9. The primary goal of the air monitoring program is to determine if the level of protection provided to the worker is sufficient to minimize the internal equivalent dose.
- a. Allowable concentration values, such as DACs, are used as an index of the degree of control needed and achieved.
  - b. Documented measurements of the airborne radioactivity concentrations are required to demonstrate that satisfactory control is achieved and maintained.
10. Air sampling is required when an individual is likely to receive an exposure of 40 or more DAC-hours in a year. Other situations requiring sampling are:
- a. to establish the need for posting of airborne radioactivity areas and to determine the need for respiratory protection for workers.
  - b. to assess unknown hazards during maintenance on systems contaminated with radioactive material or when there is a loss of process controls.

- c. to assist in determining the type and frequency of bioassay measurements needed for a worker.
- d. to provide an estimate of worker exposures for situations where bioassay measurements may not be available or their validity is questionable.
- e. to develop baseline airborne radioactivity levels and verify containment integrity as necessary during startup of a new facility or new operation within an existing facility.
- f. where respiratory protection devices for protection against airborne radionuclides have been used.
- g. real-time monitoring is needed as necessary to detect and provide warning of increases in airborne radioactivity levels that warrant immediate actions to terminate the inhalation of airborne radioactive material.

## B. THE NATURE OF AIRBORNE RADIOACTIVITY

Objective 2.06.02

1. Airborne radioactive contaminants are generally divided into three categories, based on the physical state of the contaminant.
  - a. Particulates
  - b. Gases
  - c. Vapors
2. Particulate contaminants are solid and liquid particles, ranging upward from molecular sizes (approximately  $10^{-3}$   $\mu\text{m}$ ), suspended in the air.
  - a. Solids may be subdivided into fumes, dusts, and smokes, which are distinguished mainly by their mode of generation.
  - b. Liquids are subdivided into mists and fogs, depending on the dispersion of the liquid particulates.
  - c. The term "aerosols" is used to collectively refer to relatively stable suspensions of either solid or liquid particles in a gaseous medium.

- d. Generally, particulates are more readily retained in the lungs than are gases, but retention of particulates is highly dependent on particle size and solubility in the lung.
  - e. While this suggests that particulate airborne contaminant sampling should measure particle size, this is not practically accomplished on a routine basis.
  - f. Certain sampling instruments utilize the characteristics of particle size to separate larger particles from smaller particles (e.g., impactors.)
  - g. This is an important factor in that the size range of particles retained in the respiratory tract is generally 1-10  $\mu\text{m}$ .
  - h. The retention of inhaled radioactive particles after deposition in the pulmonary region of the lung is strongly influenced by the dissolution characteristics of the particles.
    - 1) Dissolution in the lungs allows clearance into the blood and the rest of the systemic circulation.
    - 2) For this reason, the various chemical forms of radioactive particles are classified with respect to their potential solubility in the lungs.
    - 3) These are Type S for the very insoluble particle that takes years to clear from the lungs; Type M for the somewhat more soluble particles that take weeks to dissolve and clear into the systemic circulation; and Type F for the relatively soluble particles that dissolve in a matter of days in the lung.
3. Gases are substances that, under normal conditions of temperature and pressure, exist in the gaseous phase.
- a. The retention of the gases in the body from poor inhalation is so radioactive gases are usually treated as an external source of exposure.
  - b. Radioactive gases typically found are the fission product gases, such as xenon and krypton, and naturally occurring radon.
  - c. While the gases contribute primarily to external exposure, the particulate daughters to which they decay can contribute to internal exposure.



4. Vapors are considered the gaseous phase of a substance that is normally a solid or liquid under normal conditions of temperature and pressure.
  - a. Airborne vapor sampling is most commonly done for radioiodine and tritium.
  - b. The contaminant may be dispersed in vapor form at abnormal conditions of temperature and pressure.
  - c. However, as the temperature and pressure conditions return to "normal," the contaminant will return to its normal solid or liquid form, or become a particulate.
  - d. Sampling methods for vapors should isolate or measure the contaminant regardless of whether the vapor or particulate form is present.

#### C. REPRESENTATIVE AIR SAMPLES

Objectives 2.06.03

1. To ensure that the sample is representative of the actual conditions.
  - a. The airborne radioactivity concentration entering the sample line must be representative of the airborne radioactivity concentration in the air near the sampling device.
  - b. The airborne radioactivity concentration entering the sampling inlet must be representative of the airborne radioactivity concentration at the point of concern, or the air that is breathed, i.e., breathing zone.
2. When obtaining an air sample, care must be taken to ensure that the sample obtained is representative of the air around the sampling device.
  - a. This is particularly important for sample lines that directly sample an air flow, such as a stack or duct monitor.
  - b. Air flow into sampling lines needs to be balanced with respect to the flow of air around the probe or sample inlet.
  - c. If there is not a relative balance between these velocities, particles may be thrown in or out of a sampling probe rather than being sampled in a representative fashion.

- d. To ensure the sample is representative, the flow rate in the sample line or inlet must be the same as the flow rate in the system, such as the duct or stack.
- 1) When the sample line velocity is equal to the system velocity at the sample point, it is called isokinetic sampling
- e. If the velocities are not the same, or *isokinetic*, then discrimination can occur for smaller or larger particles. This occurs because the inertia of the more massive particles prevents them from following an airstream that makes an abrupt directional change.
- 1) If the velocity of the sample airstream is  $>$  the velocity of the system airstream, then the larger particles can not make the abrupt change and are discriminated against in the sample, i.e., the smaller particles are collected more efficiently.
- 2) If the velocity of the sample airstream is  $<$  the velocity of the system airstream, then the small particles do make the abrupt change and are discriminated against in the sample, i.e., the larger particles are collected more efficiently.
- f. To minimize particle losses, sampling lines should be as short (less than six feet preferred) and straight as possible to avoid sample deposition along the walls of the tube. When possible, sample lines should be vertical instead of horizontal to prevent gravimetric settling of large particles.
- g. The sampling line should have no more than one bend and be made of conducting material.
3. There are other factors to consider for maximizing the efficiency of airborne radioactivity detection.
- a. Self-absorption losses, e.g., dust loading, should be minimized. This is especially critical for alpha detection.
- b. Air in-leakage between the sample intake and the sample collection medium should be eliminated to the greatest degree possible by instrument design.

Objective 2.06.04

See Fig. 1 - "Isokinetic Sampling"

- c. The system and mechanisms within the instrument for sample collection should be designed and constructed to minimize deterioration and to facilitate decontamination. This is more critical in areas with corrosive atmospheres.
4. When obtaining an air sample, care must be taken to ensure that the sample obtained is representative of the air at the point of interest (the breathing zone).
    - a. Depending on the source of the airborne contaminant, the concentrations within a work area can vary over several orders of magnitude.
    - b. The sample taken should be representative of the air entering the nose and mouth of the individual workers since the data obtained may be used to estimate potential worker intakes.
    - c. The best method to ensure a representative breathing zone sample is to sample the air at the individual's nose and mouth.
    - d. This sampling method may not always be practical and general work area sampling may be the alternative.
    - e. Care must be exercised in the selection of the number and placement of the general area air samplers to ensure that the sample is as representative as possible.

#### D. BASIC SAMPLING METHODS

1. Basically, three types of samples are collected:
  - a. A volumetric sample in which part of the atmosphere is isolated in a suitable container, providing the original concentration of the contaminant at a particular place and time.
  - b. An integrated sample which concentrates the contaminant on some collecting medium, providing an average concentration over the collection time. (Sometimes called a "grab" sample if collected in a short period of time.)
  - c. A continuous sample where the sample air flow is directed past or through a detection device providing a measurement of the activity per unit volume of air.

2. Breathing zone air monitoring should be performed continuously in areas where workers are likely to exceed 40 DAC-hr exposure in a year.

Breathing zone air monitoring is used to identify possible worker internal exposure and the need for follow-up bioassay measurements.

3. Source-specific air sampling is performed near an actual, or likely, release point in a work area.

This is typically used to verify containment integrity, documenting airborne radioactivity levels, and providing guidance on personnel protective measures (e.g., determining when respiratory protection is required).

4. Grab air sampling is used for temporary or nonroutine (e.g., emergency response) situations and as a backup for other types of air sampling in the event of equipment failure.

- a. Portable air sampling equipment is typically used for operations requiring a grab sample.
- b. Sample flow rates may vary depending upon the specific application, but should always allow collection of a sample volume adequate to ensure the minimum detectable activity of the sampling and counting system is no greater than 2% of an ALI.

5. There are six general methods for obtaining samples or measurements of airborne radioactivity concentrations.

Objective 2.06.05

- a. Filtration
- b. Volumetric
- c. Impaction/impingement
- d. Adsorption
- e. Condensation/dehumidification
- f. In-line/flow-through detection

6. Filter samplers employ filtration of the air as the method of concentrating the airborne radioactive particulate (aerosol) contaminants.

- a. Filtration is the most common sampling method employed for particulates because it is relatively simple and efficient, but is ineffective as a sampling method for gases and vapors.
  - b. The filter sampling technique employs an air mover, such as a vacuum pump, to draw air through the removable filter medium at a known flow rate for a known length of time.
    - 1) If the flow rate and sample time are known, the total volume collected can be calculated.
    - 2) After analysis of the filter medium to determine the amount of radioactive material collected on the filter at the time of the sample, the airborne concentration can also be calculated.
  - c. The filtration medium selected for a sample depends on several factors: the collection efficiency required, the flow resistance of the medium, and the mechanical strength of the filter, pore size, the area of the filter, the background radioactive material of the filter, cost, self-absorption within the filter, and chemical solubility.
  - d. A wide choice of filters is available. The most common types are:
    - 1) Cellulose-asbestos filters
    - 2) Glass fiber filters
    - 3) Membrane filters

Membrane filters are manufactured with various pore sizes and can be dissolved in organic solvents and analyzed in a counter, e.g., a liquid scintillation counter.
7. Volumetric samplers employ a sample container into which the sample is drawn, by some method, and isolated for analysis.
- a. Several methods are employed to draw the sample into the container.
    - 1) The container may be evacuated by a vacuum pump and isolated away from the sample location. The container is opened at the sample location to draw the air into the container. The sample is sealed in the container and removed for analysis.

- 2) An air mover, such as a vacuum pump, may be employed at the sample location to draw a representative atmospheric sample into the container.
  - 3) The container could be filled with water, isolated and taken to the sample location. The water is poured out of the container, drawing the air sample into the container as the water pours out.
  - b. This method can be employed for particulates, gases, and vapors.
8. Impingers or impactors concentrate particulate contaminants on a prepared surface by abruptly changing the direction of the sample air flow at some point in the sampler.
- a. Particles are collected on a selected surface as the airstream is sharply deflected. Due to their inertia, the particles are unable to follow abrupt changes in airstream direction.
  - b. The surface on which the particles are collected must be able to trap the particles and retain them after impaction. Several methods are commonly used to trap the particles, such as:
    - 1) Coating the collection surface with a thin layer of grease or adhesive.
    - 2) Immersing the collection surface in a fluid, such as water or alcohol, which is then analyzed after the sample is collected.
  - c. Impingers and impactors may utilize several stages or impingement distances to discriminate for or against different particle sizes.
  - d. Impactors are frequently used to isolate particles larger than the undesired smaller particles, such as transuranics over radon daughters, or radon daughters over fission products.
9. Adsorber sampling devices concentrate the contaminants by causing them to adhere to the surface of the adsorption medium.
- a. Adsorption is the adhesion of a substance to the surface of another substance through bonding.

- b. The adsorption medium is granulated or porous to increase the surface area available for trapping of the contaminant.
  - c. The technique employs an air mover to draw and collect the sample through the adsorption media.
  - d. Adsorbers, such as activated charcoal, silica gel, and silver zeolite, are commonly used to collect organic vapors and non-reactive gases and vapors.
    - 1) Activated charcoal is used primarily for radioiodine sampling, but does trap noble gases, such as xenon, krypton and argon.
    - 2) Silica gel is primarily used for tritium oxide vapor sampling.
    - 3) Silver zeolite is used for radioiodine sampling when trapped noble gases would interfere with the radioiodine analysis.
  - e. Particulates would be "filtered" by the absorption media and must be filtered out before the adsorption process to prevent interference during the analysis of the media.
10. Condensation or dehumidifier sampling devices employ a "cold trap" to condense water vapors in the sampled atmosphere and provide a liquid sample for further analysis.
- a. Some means, such as liquid nitrogen or a refrigeration unit is utilized to cool the condensation surface and cause condensation of the water vapor as it passes over the cold surface.
  - b. The collected water is frequently analyzed using a liquid scintillation counter.
  - c. Calculations must include the relative humidity and temperature of the air at the time the sample is taken to determine the concentration of water vapor per unit volume of air.
  - d. This technique is normally only applied for sampling tritium oxide vapor (HTO or T<sub>2</sub>O).
11. In-line or flow-through samplers employ an air mover to direct the sample air flow through or past the detection device.

- a. This method is employed for radionuclides which are difficult to collect or detect by other means.
  - b. Because the air flow passes directly outside the detector or actually through the inside of the detector, the air must be filtered for particulates or vapors that could accumulate on or in the detector.
  - c. In-line detectors are used to measure gaseous activity after filtration and adsorption have been accomplished.
  - d. Flow-through detectors are employed for radionuclides, such as tritium, which emit low-energy radiation, that could not otherwise pass through the detector window.
12. The various sampling methods may be combined into one sampler or monitor.
- a. Some *samplers* employ the filtration method for particulates, the adsorption method for vapors and the volumetric grab-sample method for gases (in that order). Some advantages of combining these methods are:
    - 1) One vacuum pump supplies the air flow for all the samples.
    - 2) All the samples are drawn at the same time to minimize the amount of time spent by the technician drawing samples.
  - b. In addition, some monitors have detectors installed to monitor each sample and provide an immediate readout as well as other capabilities, such as alarms, data records, process controls, and trending.

#### E. SELECTION OF THE AIR SAMPLING METHOD

1. It is critical that the proper air sampling method and equipment be selected because:
  - a. The data obtained must be meaningful and accurate to adequately assign radiological control measures.
  - b. Improper selection and use may incorrectly indicate a safe environment where an airborne radiological hazard exists or leads to unneeded postings where no hazard exists.
2. The general considerations for the selection of an air sampling method include several factors.

Objective 2.06.06



- a. The environmental conditions in the area where the sample is to be obtained.
  - 1) Humid conditions may preclude the use of some methods, such as paper filtration devices or charcoal canisters, because water vapor loading of the medium will change the collection efficiency and flow rate.
  - 2) High temperature environments may cause some samplers to overheat if run for long periods of time.
  - 3) Explosive gases may be present which could present an explosion hazard for samplers with electric motors not designed for such environments.
  - 4) Dusty areas could cause excessive sample loading which will reduce sampler flow rates and potentially overheat the sampler.
  - 5) Corrosive environments may lead to the deterioration of the sampling device.
- b. The physical characteristics of the area in which the sample is to be obtained.
  - 1) An electrical outlet may not be available or close, and a battery powered sampler would be better suited.
  - 2) Close spaces or passages may preclude the use of movable CAMs or heavy samplers.
- c. The energy and type of radiation of the radionuclide being monitored. This will dictate the type of CAM or analysis equipment required to determine the airborne radioactivity concentration.
- d. The expected concentration level. This will determine the length of sample time and type of sampler required.
  - 1) Low-level concentrations will require larger volumes to reduce statistical errors and meet minimum sensitivity levels of the analysis equipment.
  - 2) Large volume samples obtained over a long time period are best obtained by samplers designed to run for long periods.

- 3) If immediate readout of information is needed, then collection and analysis are done at the same time.
  - 4) If not, then samples may be taken and removed to a central analysis location.
- e. The physical state of the airborne contaminant. Dependent upon whether the contaminant is either gas, vapor or aerosol, will dictate the type of sampler and sample medium that is required.
  - f. The type of survey required. Specific methods, such as breathing zone samples, routine general area samples, general work area samples, general trending over time, etc., also determines the type of equipment that is selected.
  - g. Procedural requirements. This may dictate a particular type of sample method and/or sample medium for a given application.
    - 1) Check the appropriate procedures prior to sampler selection.
    - 2) Ask supervision and experienced technicians for their input.

#### F. PRIMARY TYPES OF AIR SAMPLERS

1. The five primary types of airborne radioactivity samplers/monitors are:
  - a. Personal air samplers (breathing zone)
  - b. High volume/flow rate air samplers
  - c. Low volume flow rate air samplers
  - d. Portable continuous air monitors (CAMs)
  - e. Installed continuous air monitoring systems
2. Personal air samplers (PAS) provide an estimate of the airborne radioactivity concentration in the air the worker is breathing during the sampling period.
  - a. The PAS may also be used to determine if the protection factor for respiratory equipment is exceeded, to compare with other workplace air samples, and to verify the effectiveness of engineered and administrative controls.

- b. Personal air samplers are small portable battery-powered devices which sample the air in the breathing zone of the worker's environment, making allowances to eliminate interferences the sampler's themselves may have on a worker's activities. Some characteristics are:
  - 1) The device contains a small battery-powered pump that is calibrated to a flow rate approximately 1/10 (2 liters per minute) the breathing rate of a worker performing light activity.
  - 2) The sampling line terminates in a filter cassette which contains the filtration medium for the radioactive particulate contaminants.
  - 3) The sample filter cassette is attached close to the nose and mouth of the individual.
- 3. Portable high volume/flow rate samplers provide an estimate of the airborne radioactivity concentration at a particular location in a short period of time. See Fig. 2 - "High Volume Sampler"
  - a. Portable high flow rate samplers are used to collect airborne aerosols on a filter paper (filtration) or on a greased planchet (impaction).
  - b. Portable high flow rate samplers can also be used to collect radioiodine samples using activated charcoal cartridges (adsorption) as long as the maximum flow rate of the cartridge is not exceeded or a correction factor is used.
  - c. These samplers do not have installed detectors and the sample must be removed from the sampler and analyzed on separate analysis equipment.
  - d. The high volume/flow rate samplers may be used to:
    - 1) Provide a routine "slice of time" estimate of the general area airborne radioactivity
    - 2) Verify boundaries of areas posted for airborne radioactivity
    - 3) Or monitor the airborne radioactivity related to a specific work activity.
  - e. High volume samplers typically use flow rates of at least 10 cubic feet per minute (cfm).

- 1) Although these samplers are noisy and not intended for continuous duty, the shorter sample times allow for greater sensitivity.
4. Low volume/flow rate samplers provide an estimate of airborne radioactivity concentrations averaged over a longer period of time at a particular location.
  - a. Portable low volume/flow rate samplers are used to collect samples for aerosols on filter paper (filtration) and radioiodine on an adsorption medium, such as an activated charcoal cartridge.
  - b. Low volume/flow rate samplers may be used to provide average airborne radioactivity estimates over a period of time for:
    - 1) Commonly traversed areas that normally have a low probability of airborne radioactivity problems
    - 2) Areas not commonly traversed with a higher probability of airborne radioactivity problems
    - 3) Backup samples in areas where airborne radioactivity problems are discovered by other means
    - 4) Work maintenance activities normally characterized by low airborne radioactivity concentrations.
  - c. Low volume samplers generally have flow rates set at approximately 20 lpm, the breathing rate of a worker performing light activity.
    - 1) Although these samplers must run longer for reasonable sensitivity, they are generally quiet and can be used for continuous duty.
5. Portable CAMs provide an estimate of airborne radioactivity concentrations averaged over time at a particular location, and provide immediate readout and alarm capabilities for preset concentrations.
  - a. These air monitors are portable low flow rate (~20 lpm) sampling systems, containing the necessary sampling devices and built-in detection systems to monitor the activity on the filters, cartridges, planchettes and/or chambers in the system.

See Fig. 3 - "Low Volume Sampler"

- b. The system may provide a visual readout device for each type of sample medium, a recording system for data, and computer functions such as data trending, preset audible and visual alarms/warning levels and alerts for system malfunctions.
  - c. Typical CAMs provide information on alpha and/or beta/gamma particulates (filtration), radioiodine activity (adsorption) and noble gas activity (volumetric chamber or in-line detector).
  - d. Portable CAMs can be utilized as:
    - 1) Low volume general area samplers
    - 2) Monitors with alarm capabilities for areas where airborne radioactivity conditions may quickly degrade
    - 3) Trending devices in selected areas
    - 4) Devices to locate system leaks, if used with the appropriate length hose or tubing.
6. Installed CAMs provide an estimate of airborne radioactivity concentrations averaged over time at a fixed, designated location, and provide immediate local and remote readout and alarm capabilities for preset concentrations.
- a. These air monitors are fixed low flow rate sampling systems, and contain the necessary sampling devices and built-in detection systems to monitor the activity of selected areas or airstreams.
  - b. The system may provide a local and remote visual readout device, a recording system for data, and computer functions such as data trending, preset audible and visual alarms/warning levels and alerts for system malfunctions.
  - c. Installed CAM applications include:
    - 1) Fixed installations capable of sampling several locations through valved sample lines.
    - 2) Stack monitors
    - 3) Duct monitors

7. Factors affecting the accuracy of airborne radioactivity measurements include:
  - a. Sample is not representative of the atmosphere being sampled
  - b. Sample is not representative of the air being breathed by the worker
  - c. Incorrect or improperly installed sampling media for the selected sampler, causing leak or improper flow rates
  - d. Malfunctioning, miss-operated, or miscalibrated sampling device, causing errors in flow rate measurements
  - e. Accuracy and operation of the timing device, causing errors in the time value
  - f. Accuracy and operation of the flow rate measuring device, causing errors in the flow rate value
  - g. Mishandling of the sample media causing cross-contamination or removal of sample material
  - h. Changes in the collection efficiency of the medium due to sample loading, humidity and other factors
  - i. Improper use or selection of analysis equipment
  - j. Inherent errors in the counting process due to sample geometry, self-absorption, resolving time, backscatter and statistical variations
  - k. Mathematical errors during calculations due to rounding of numbers and simple mistakes
  - l. Incorrect marking of samples and inaccurate recording of data
8. It is important that the personnel performing the sample collection and analysis minimize the magnitude of these errors to ensure that accurate and reliable data is obtained for the assignment of internal exposure control methods.

## G. BASIC AIR SAMPLE CALCULATIONS

1. Once the air sample is collected and analyzed, calculations must be performed to determine the amount of activity per unit volume.
2. The specific calculations for particular sampling methods are not covered in this lesson; however, some basics are necessary for each calculation.
3. The analysis of the sample provides the activity of the sample at the time of the sample analysis.
  - a. This value may be corrected for decay for the time period between when the sample was taken to when it was analyzed.
    - 1) This is especially true for short-lived radionuclides.
    - 2) This correction may not be necessary for very long-lived radionuclides.
  - b. The volume of the sample must be determined from the sample data recorded, such as flow rates at the beginning and end of the sample, and sample time period.
  - c. The basic calculation listed below would also include the conversions necessary for the desired units such as dpm/liter to  $\mu\text{Ci/cc}$ .
  - d. The calculation would also include correction factors, as necessary, for:
    - 1) Interference of other radionuclides, such as radon and thoron daughters
    - 2) Collection efficiency
    - 3) Counter efficiency
    - 4) Self-absorption by the sample media
    - 5) Counter background.
    - 6) Temperature and pressure as applied to flow rate
4. Many errors are inherent or induced in the sampling analysis process and affect the accuracy of the resulting data.

5. The operator of the sampling and analysis equipment must be aware of these points of error to ensure the resulting data is as accurate as possible.

*(Insert site specific material here)*

Objective 2.06.09

### III. SUMMARY

#### A. Review major points

1. Purpose and objectives of airborne radioactivity sampling
2. The nature of airborne radioactivity
3. Representative air samples
4. Basic sampling methods
5. Selection of the air sampling method
6. Primary types of air samplers
7. Basic air sample calculations

#### B. Review learning objectives

### IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.



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**Course Title:** Radiological Control Technician  
**Module Title:** Respiratory Protection  
**Module Number:** 2.07

**Objectives:**

- 2.07.01 Explain the purpose of respiratory protection standards and regulations.
- 2.07.02 Identify the OSHA, ANSI, and DOE respiratory protection program requirements.
- 2.07.03 Identify the standards which regulate respiratory protection.
- 2.07.04 Describe the advantages and disadvantages (limitations) of each of the following respirators:
- a. Air purifying, particulate removing filter respirators
  - b. Air purifying, Chemical Cartridge and Canister respirators for Gases and Vapors
  - c. Full-face, supplied-air respirators
  - d. Self-contained breathing apparatus (SCBA)
  - e. Combination atmosphere supplying respirators
- 2.07.05 Define the term protection factor (PF).
- 2.07.06 State the difference between a qualitative and quantitative fit test.
- 2.07.07 State the recommended physical functions the subject must perform during a respirator fit test.
- 2.07.08 State how the term protection factor (PF) is applied to the selection of respiratory protection equipment.
- 2.07.09 State the general considerations and considerations for the nature of the hazard when selecting the proper respiratory protection equipment.
- 2.07.10 Identify the types of respiratory equipment available for use at your site.
- 2.07.11 Identify the quality specification breathing air must meet.

**References:**

1. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5<sup>th</sup> ed.; Pacific Radiation Corporation; 2008.
2. "Introduction to Health Physics"; Cember, Herman; 4<sup>nd</sup> ed.; McGraw-Hill Medical; 2008.
3. "Limits for Inhalation of Radon Daughters by Workers", ICRP Publication 32.
4. "Operational Health Physics Training Course", Moe, H.J., et. al., Argonne National Laboratory, Argonne, 88-26.
5. "Radiation Detection and Measurement", Knoll, G., John Wiley and Sons, New York, 2000.
6. 10 CFR 835, "Occupational Radiation Protection", 2007.
7. "Practices of Respiratory Protection", ANSI Z88.2, 1992.
8. "Manual of Respiratory Protection Against Airborne Radioactive Material", NUREG-0041, 1976.
9. Respiratory Protection, Federal OSHA, 29 CFR 1910, 134.

10. DOE-STD-1167-2003, DOE Respiratory Acceptance Program for Supplied-Air Suits
11. CGA G7.1-1989, Breathing Air, Commodity Specification for Air
12. 10 CFR 851, "Worker Protection Programs", 2007.
13. DOE Order 440.1B (2007), Worker Protection Management for DOE (including National Nuclear Security Administration) Federal Employees
14. ANSI Z88.2 (1992)

**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

Internal dosimetry controls require the use of engineering controls to prevent the internal deposition of radioactive and non-radiological contaminants. However, when engineering and administrative controls are not available or feasible, respiratory protection may be necessary. The RCT should know and apply the considerations used in determining the respiratory protection equipment that is most appropriate for the job. Inappropriate use of or the use of the wrong respiratory protection equipment may result in undesirable health effects.

## C. Overview of Lesson

1. Requirements and regulations
2. Types of equipment
3. Protection factors
4. Fit testing
5. Selection of respirators
6. Site respiratory equipment
7. Supplied air quality testing
8. Sorbents and protection against radioiodines
9. Communications

## D. Introduce Objectives

O.H.: Objectives

**II. MODULE OUTLINE****A. REQUIREMENTS AND REGULATIONS**

## 1. DOE Requirements

10 CFR 851, for contractors, and DOE Order 440.1B, for Federal employees, mandates the requirements for a respiratory protection program contained in ANSI Z88.2 and 29 CFR 1910.134.

## 2. OSHA REGULATIONS - 29 CFR 1910.134

Objective 2.07.01

Purpose: Specify the minimal acceptable program which must contain or address the following:

- a. Written procedures and program
- b. Respirator selection
- c. The user shall be instructed and trained in proper use of respirators
- d. Respirators shall be cleaned and disinfected after each use
- e. Respirators stored in a clean, sanitary location
- f. Respirators inspected routinely and replaced when necessary
- g. Appropriate surveillance of work area conditions and degree of employee exposure or stress
- h. Regular evaluation of program
- i. Persons should be physically able to use respiratory protection equipment as certified by a licensed health care practitioner
- j. NIOSH approved respirators shall be used

3. ANSI Z88.2 - 1992: *Further specifies the minimal acceptable program*

Objective 2.07.02

Objective 2.07.03

- a. Individual exposures limited by both inhalation and skin absorption
- b. Air sampling and bioassays

- c. Engineering controls are primary method
  - d. When an individual is exposed to greater than the specified DAC or other exposure limits
  - e. Respiratory protection equipment must be NIOSH approved
  - f. If allowance for use of respiratory protection equipment is made,
    - 1) Protection factor must be sufficient to limit the annual dose considering the anticipated peak exposure concentration and associated DAC
    - 2) If exposure is later found to be greater than estimated, corrected value shall be used
    - 3) Surveys and bioassays conducted as appropriate to evaluate actual exposures
    - 4) Written procedures must be established
    - 5) Determination by a qualified health care professional of a user's physical capability
    - 6) A written policy statement must be issued
      - a) Engineering controls
      - b) Routine, non-routine and emergency use
      - c) Periods of use
    - 7) Each user must be advised upon failure of equipment, physical stress or deterioration of operating conditions
    - 8) Equipment is appropriate for environment and special equipment, such as communication devices issued when needed
    - 9) Emergency use equipment must be specifically certified as such by NIOSH
- If less than estimated, the corrected value may be used
- Objective 2.07.04

## B. TYPES OF EQUIPMENT

## 1. Air purifying, particulate-removing filter respirators

"dust," "mist" or "fume"  
respirators

## a. Description

- 1) Filtering action removes particulate
- 2) Operate in negative pressure (NP) mode
- 3) Exception is a special type of powered air purifying respirator that is designed to never be negative pressure.

## b. Limitations

- 1) Do not provide oxygen
- 2) No protection against gases or vapors
- 3) Should not be used for abrasive blasting operations
- 4) Battery operated respirators are limited by battery life
- 5) High humidity may increase breathing resistance as paper elements become water saturated
- 6) Not to be used in IDLH atmospheres

NEVER to be worn in  
oxygen-deficient  
atmospheres

## 2. Air Purifying, Chemical Cartridge and Canister Respirators for Gases and Vapors

## a. Description - use cartridges or canisters containing chemicals to remove specific vapors and gases.

The difference between a  
cartridge and a canister is  
the volume of the sorbent.  
Canisters have longer  
capacity and are used in  
gas masks.

## b. Limitations

- 1) Do not provide oxygen

NEVER to be worn in  
oxygen deficient  
atmospheres

- 2) Unless approved by DOE, no credit for protection against radioactive gases and vapors
  - 3) High humidity shortens life of the sorbent material and increases breathing resistance
  - 4) Not to be used in IDLH atmospheres
3. Atmosphere Supplying Respirators - Air
- a. Description
    - 1) Use central source of breathing air delivered to wearer through a line or hose
    - 2) Either tight-fitting facepiece or loose-fitting hood/suit
    - 3) Demand device - during inhalation there may be negative pressure in the mask
    - 4) Pressure demand device - positive air pressure inside mask is maintained at all times
    - 5) Continuous-flow air line - is designed to create positive pressure in facepiece
  - b. Limitations (not for emergency escape or rescue)
    - 1) Not used in IDLH atmospheres
    - 2) Trailing air supply hose severely limits mobility
    - 3) Length of hose, number of potential users and pressure of the supply system are interdependent. No more than five sections of hose with a maximum length of 250 feet.
    - 4) Control of air quality is essential
    - 5) "Bubble suits" must be tested for exact conditions of use



## c. Special Considerations

- 1) Follow all manufacturers instruction and written facility/site procedures
- 2) If all hoses and fittings are same then a single pressure gauge is appropriate
- 3) For situations where each user has different hose lengths, different number of connection or different air pressure requirements then a separate pressure gauge should be used

## 4. Atmosphere Supplying Respirators - Self-Contained Breathing Apparatus (SCBA)

Air supply may last 3 minutes to four hours

## a. Description

- 1) Allows the user to carry a respirable breathing supply
- 2) There are two groups of SCBAs closed circuit and open circuit
  - a) Closed circuit SCBAs - "rebreathing" device
  - b) Open circuit SCBA exhausts the exhaled air to the atmosphere
  - c) Two types of open circuit SCBA are available, "demand" or "pressure demand"
    - Demand SCBA - air flows into facepiece only on demand of the wearer
    - Pressure demand - maintains positive pressure in facepiece at all times regardless of "demand" of user

Designed primarily for 1-4 hours use in toxic atmospheres

Service life is shorter

When the person inhales note: demand-type SCBA does not provide any higher degree of protection against airborne contaminants than air-purifying respirator with same facepiece, but it does provide protection against oxygen deficiency

Recommended for emergency use, escape and rescue

- b. Combination atmosphere supplying respirators
- 1) Combination Pressure Demand Breathing Apparatus provides respiratory protection for personnel who must work in atmospheres that are IDLH  
Equipped with small air cylinder in case primary air supply (hose line) is interrupted
  - 2) Dual-purpose Breathing Apparatus combines all capabilities of SCBA and an air line respirator in one unit
- c. Limitations of the pressure and demand SCBA
- 1) Air supply is limited
  - 2) Bulky and heavy
  - 3) Demand type not for fire fighting  
10CFR20 Appendix R Section H
- d. Special considerations of the pressure demand SCBA
- 1) Only pressure-demand type SCBA should be selected for emergency use, rescue and reentry into contaminated area  
Section 5.5 of NUREG 0041
  - 2) Performance of SCBAs in high temperature environments, such as fires may lead to rapid deterioration of components
- B. PROTECTION FACTORS
1. Overall protection afforded by a given respirator design is defined in terms of its protection factor (PF)  
Objective 2.07.05
  2. An assigned PF is defined as the level of protection that would be expected from a class or type of respirator to a properly fitted and trained user.
  3. Application of PFs
  4. 29 CFR 1910.134 Protection Factors

Table 1 - "Assigned Protection Factors"

## C. FIT TESTING

## Objective 2.07.06

## 1. Definitions

## a. Qualitative fit test:

Test to determine if there is any mask leakage, usually using irritant smoke

## b. Quantitative fit test:

Test to determine quantity of mask leakage and assign a "fit factor," an oil or dust particles are the typical challenge atmospheres used

## 2. Qualitative fit tests are sometimes performed in lieu of quantitative fit tests

## a. Can use challenge atmospheres such as Isoamyl Acetate (banana oil) or irritant smoke (e.g. stannic chloride or titanium tetrachloride)

## b. A qualitative fit test uses the same series of exercises as quantitative fit testing

Irritant smoke tests are most effective

## c. An abbreviated qualitative "fit check" may be used prior to entry into a contaminated area

## 3. At least a qualitative test must be performed - a negative pressure type is typical.

## 4. Additional factors to be considered

## a. Use of communication devices

## b. Sorbent canisters with respirators

## 5. Respirator face pieces and cartridges must be periodically tested

## a. Test a portion of particulate cartridges upon procurement

Minimum requirement - each site may be more restrictive

## b. Test all particulate cartridges prior to re-use

## c. Respirator facepieces are tested annually using:

## 1) Test head mannequin

Penetration value of less than or equal to 0.003% is acceptable

- |   |   |
|---|---|
| <ul style="list-style-type: none"> <li>2) Challenge atmosphere with a light scattering photometer</li> <li>3) Fit check by user</li> </ul>  |   |
| <ul style="list-style-type: none"> <li>6. Fit testing of individual is normally quantitative           <ul style="list-style-type: none"> <li>a. Involves measurement of a challenge atmosphere both inside and outside respiratory facepiece</li> <li>b. A "fit factor" is determined by dividing concentration of challenge atmosphere outside respirator by concentration inside facepiece</li> <li>c. An oil mist may be used as a challenge atmosphere or particle measuring instrument (e.g., Portacount)</li> <li>d. Oil mist apparatus uses photometry as system for measuring challenge and breathing zone atmospheres</li> <li>e. Subject generally performs the following functions during fit testing:               <ul style="list-style-type: none"> <li>1) Normal breathing</li> <li>2) Deep breathing</li> <li>3) Moving head from side to side</li> <li>4) Moving head up and down</li> <li>5) Frown</li> <li>6) Talking</li> <li>7) Running in place</li> <li>8) Normal breathing</li> </ul> </li> </ul> </li> </ul> | <p>Objective 2.07.07</p> <p>Note: DOP has been discontinued as a challenge atmosphere since it is a potential carcinogen</p> <p>Highlight significance of functions as related to job performance</p> |
| <p>D. SELECTION OF RESPIRATORS</p> <ul style="list-style-type: none"> <li>1. Most critical factor: the protection factor for respirator device to be used needs to be adequate to control radiation dose, considering the work area concentration</li> <li>2. Only NIOSH approved respirators shall be selected.</li> <li>3. General considerations. The selection of a proper respirator for any given situation shall require consideration of the following factors:</li> </ul>  | <p>Objective 2.07.08</p> <p>29 CFR 1910.134</p> <p>Objective 2.07.09</p>  |

- a. The nature of the hazard
  - b. The characteristics of the hazardous operation or process
  - c. The location of the hazardous area with respect to a safe area having respirable air
  - d. The period of time for which respirator protection may be provided
  - e. The activity of workers in the hazardous area
  - f. The physical characteristics, functional capabilities, and limitations of respirators of various types
  - g. The respirator-protection factors and respirator fit
  - h. Requirement of facility/site written procedures
4. Nature of Hazard. The following factors concerning the nature of the hazard requiring the use of respirators shall be considered in respirator selection:
- a. Type of hazard
    - Oxygen deficiency
    - Contaminant
  - b. Physical properties
  - c. Chemical properties
  - d. Physiological effects on the body
  - e. Actual concentration of a toxic material or airborne radioactivity level both average and peak
  - f. Whether the hazard is an immediately-dangerous-to-life-or-health (IDLH) concentration
  - g. Warning properties
5. Recognition and evaluation of the respiratory hazard (oxygen deficiency or contaminant(s)) shall be an essential part of selecting a respirator except in emergency or rescue operations. Initial monitoring of the respiratory hazard shall be carried out to obtain data needed for the selection of proper respiratory protection. The data should include:

- a. Identification of the type of respiratory hazard
    - 1) Oxygen deficiency
    - 2) Specific contaminant(s)
  - b. Nature of contaminant(s)
    - 1) Particulate matter
    - 2) Vapor(s) or gas(es)
  - c. Concentration of respiratory hazard
6. The following factors concerning the hazardous operation or process shall be taken into account in selecting the proper respirator:
- a. Operation or process characteristics both as-built and modified
  - b. Work-area characteristics
  - c. Materials, including raw materials, end products, and byproducts (actual and potential)
  - d. Worker activities

E. SITE RESPIRATORY EQUIPMENT

Objective 2.07.10

*(Insert site specific material here)*

F. SUPPLIED AIR QUALITY TESTING

1. Referenced in 29 CFR 1910.134 Objective 2.07.11
  - a. Compressed breathing air shall meet at least quality specification for Grade D breathing air
  - b. Breathing air specifications are listed in Compressed Gas Association G 7.1-1989
2. No explicit limit for water vapor but it is a contaminant
3. Acceptable analytical procedures for measuring the respirable air components

4. Frequency of performing air quality tests is recommended by ANSI Z88.2-1992
  - a. For bottled air systems received from a supplier that does not fill cylinders with any other gasses, the tests should check 10% of the cylinders from each lot for ppm CO and odor. In addition, if the supplier fills cylinders with gas other than air, analyze **all** cylinders for percent oxygen.
  - b. For facilities which generate respirable air, the sampling should be performed:
    - 1) Prior to each lot fill
    - 2) Once during the lot fill
    - 3) Once upon completion of the lot fill
  - c. For compressed air supply systems sampling frequency is best performed prior to each use of a specific manifold system
5. Separate breathing air supply and distribution system is the ideal source or worker-supplied air

In cases of heavy usage then a daily check of the system may be more appropriate.

#### G. SORBENTS AND PROTECTION AGAINST RADIOIODINES

1. The regulations specifically prohibit the use of PFs for canister sorbents as protection against radioiodine atmospheres

The efficiency of the charcoal canister is dependent upon:

  - a. chemical form of the radioiodine,
  - b. humidity of the atmosphere,
  - c. and breathing rate of the user.
2. Approval may be obtained to use PF's for sorbent cartridges
3. Examples of limiting conditions of use (user must follow manufactures instructions and DOE approval criteria):
  - a. Total challenge in the work place (radioactive iodine, non-radioactive iodine or the halogenated compounds) may not exceed 1 ppm

- b. Temperature in the work area may not exceed 100 EF.
- c. Respirator wearers must have demonstrated a fit factor greater than 100 for half mask, 1000 for full face piece.
- d. Service life is 8 hours maximum. This is calculated from the time the canister is unsealed and includes periods of non-use.
- e. Canisters will not be used in the presence of organic solvents, vapors, or chemicals.
- f. Canisters must be stored in sealed humidity-barrier packaging in a cool, dry environment.

#### H. COMMUNICATIONS

- 1. Conventional respirators distort the human voice to some extent
- 2. Special attachments are often needed to ensure adequate communications
  - a. Speaking diaphragm
  - b. Various methods of electronically transmitting and amplifying speech through the respirator
  - c. Any communication device that is an integral part of respirator must be part of NIOSH approval

#### IV. SUMMARY

- A. Review major topics
  - 1. Requirements and regulations
  - 2. Types of equipment
  - 3. Protection factors
  - 4. Fit testing
  - 5. Selection of respirators
  - 6. Site respiratory equipment
  - 7. Supplied air quality testing



8. Sorbents and protection against radioiodines
9. Communications

B. Review learning objectives

## V. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.

**Course Title:** Radiological Control Technician  
**Module Title:** Radioactive Source Control  
**Module Number:** 2.08

**Objectives:**

- 2.08.01 Describe the requirements for radioactive sources per 10 CFR 835.
- 2.08.02 Identify the characteristics of radioactive sources that must be controlled at your site.
- 2.08.03 Identify the packaging, marking, and labeling requirements for radioactive sources.
- 2.08.04 Describe the approval and posting requirements for radioactive materials areas.
- 2.08.05 Describe the process and procedures used at your site for storage and accountability of radioactive sources.

**References:**

1. 10 CFR 835, "Occupational Radiation Protection," (2007).

**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

Radioactive sources are used for response checks in the field, functional checks, and calibration of instruments and monitors to traceable standards. To ensure the safety and welfare of all personnel it is important to maintain control of radioactive sources. Radioactive sources are controlled to minimize the potential for:

- Spread of contamination
- Unnecessary exposure to personnel
- Loss or theft
- Improper disposal

## C. Overview of Lesson

1. Requirements
2. Control of sources
3. Receipt
4. Radioactive Materials Storage Areas
5. Inventory and transfer
6. Surveys
7. Leak test
8. Source disposal

## D. Introduce Objectives

O.H.: Objectives

**II. MODULE OUTLINE**

Objective 2.08.01

## A. 10 CFR 835

In accordance with the 10 CFR 835 Subpart M, the following provisions apply to sealed sources:

## 1. §835.1201 Sealed Radioactive Source Control

Sealed radioactive sources shall be used, handled, and stored in a manner commensurate with the hazards associated with operations involving the sources.

## 2. §835.1202 Accountable Sealed Radioactive Sources

(a) Each accountable sealed radioactive source shall be inventoried at intervals no to exceed six months. This inventory shall:

- (1) Establish the physical location of each accountable sealed radioactive source;
- (2) Verify the presence and adequacy of associated postings and labels; and
- (3) Establish the adequacy of storage locations, containers, and devices.

(b) Except for sealed radioactive sources consisting solely of gaseous radioactive material or tritium, each accountable sealed radioactive source shall be subject to a source leak test upon receipt, when damage is suspected, and at intervals not to exceed six months. Source leak tests shall be capable of detecting radioactive material leakage equal to or exceeding 0.005 microcurie.

(c) An accountable sealed radioactive source is not subject to periodic source leak testing if that source has been removed from service. Such sources shall be stored in a controlled location, subject to periodic inventory and subject to source leak testing prior to being returned to service.

(d) An accountable sealed radioactive source is not subject to periodic inventory and source leak testing if that source is located in an area that is unsafe for human entry or otherwise inaccessible.

- (e) An accountable sealed radioactive source found to be leaking radioactive material shall be controlled in a manner that minimizes the spread of radioactive contamination.

Objective 2.08.02

## B. CONTROL OF SOURCES

*(Insert site specific information here)*

### 1. Types of Sources:

- a. Accountable sealed radioactive source means a sealed radioactive source having a half-life equal to or greater than 30 days and an isotopic activity equal to or greater than the corresponding value provided in Appendix E of 10 CFR 835.
- b. Sealed radioactive source means a radioactive source manufactured, obtained, or retained for the purpose of utilizing the emitted radiation. The sealed radioactive source consists of a known or estimated quantity of radioactive material contained within a sealed capsule, sealed between layer(s) of non-radioactive material, or firmly fixed to a non-radioactive surface by electroplating or other means intended to prevent leakage or escape of the radioactive material.
- c. Source leak test means a test to determine if a sealed radioactive source is leaking radioactive material.

### 2. Responsibilities:

- a. It is important that the following actions be done:
  - 1) establishing the program
  - 2) maintaining records related to the accountability and control of accountable sealed radioactive sources for a facility
  - 3) providing each source custodian with an inventory list of accountable sealed radioactive sources assigned to him or her
  - 4) assisting the source custodian in training source users

- b. The source custodian:
  - 1) should be responsible for ensuring that tests to establish the integrity of an accountable sealed radioactive source are conducted and inventory checks are performed at least every 6 months.
  - 2) should maintain records of the storage and use locations of all assigned accountable sealed radioactive sources.
  - 3) should be trained as a radiological worker prior to being designated as a source custodian.
  - 4) should notify and obtain approval of the RCO prior to:
    - a) any major changes in the use of a sealed radioactive source
    - b) on-site transfer of a sealed radioactive source to a new permanent storage location
    - c) modification of a device containing a sealed radioactive source
    - d) disposal or off-site transfer of a sealed radioactive source
    - e) any procurement or acquisition of additional sealed radioactive sources
  - 5) should also notify the RCO in the event of the loss or damage to any accountable sealed radioactive source
- c. The source user:
  - 1) should be an individual trained by the RCO and the source custodian to use either accountable or exempt sealed radioactive sources
  - 2) should be trained as a radiological worker and receive appropriate training on handling their specific sealed radioactive source(s).

### C. RECEIPT

Prior to receipt of accountable sealed radioactive sources, the RCO should assign the sources to the proper source custodians. Immediately upon receipt of accountable sealed radioactive

sources, the RCO should be notified. The packaging should be inspected for damage and a contamination and radiation survey performed. The RCO should perform receipt surveys (RCS 431.3). A source integrity test shall be performed upon receipt if visible damage to the package exists (10 CFR 835.405), or prior to initial use. The source custodian should be notified of the arrival of the sealed sources to ensure that proper accountability and control are initiated. The sources should be placed into storage or into the device in which they will be used. The source custodian and site's records should be updated to include the new sources received.

#### D. LABELING AND STORAGE OF RADIOACTIVE MATERIAL

Objective: 2.08.03

*(Insert site specific information here)*

##### 1. §835.605 Labeling items and containers.

Except as provided in §835.606, each item or container of radioactive material shall bear a durable, clearly visible label bearing the standard radiation warning trefoil and the words "Caution Radioactive Material" or "Danger", Radioactive Material." The label shall also provide sufficient information to permit individuals handling or using the items or containers, or working in the vicinity of the items or containers, to take precautions to avoid or minimize exposures.

##### 2. §835.606 Exceptions to labeling requirements.

- (a) Items and containers may be excepted from the radioactive material labeling requirements of §835.605 when:
- (1) Used handled, or stored in areas posted and controlled in accordance with this subpart and sufficient information is provided to permit individuals to take appropriate protective actions to avoid or control exposures; or
  - (2) The quantity of radioactive material is below 1/10 the values specified in Appendix E to 10 CFR 835 and less than 0.1 Ci; or
  - (3) Packaged, labeled, and marked in accordance with the regulations of the Department of Transportation or DOE Orders governing radioactive material transportation; or

- (4) Inaccessible, or accessible only to individuals authorized to handle or use them, or to work in the vicinity; or
  - (5) Installed in manufacturing, process, or other equipment, such as reactor components, piping, and tanks; or
  - (6) The radioactive material consists solely of nuclear weapons or their components.
- (b) Radioactive material labels applied to sealed radioactive sources may be excepted from the color specifications of 10 CFR 835.601 (a).

Objective: 2.08.04

## E. RADIOACTIVE MATERIAL AREAS

*(Insert site specific information here)*

### 1. Definitions

- (a) Radioactive Material Area means any area within a Controlled Area, accessible to individuals, in which items or containers of radioactive material exist and the total activity of radioactive material exceeds the applicable values provided in Appendix E to 10 CFR 835.
- (b) Radioactive Material Area Posting The words “Caution, Radioactive Material(s)” shall be posted at each Radioactive Material Area [835.603(g)].

### 2. §835.604 Exceptions to posting requirements

- (a) Areas may be excepted from the posting requirements of §835.603 for periods of less than 8 continuous hours when placed under continuous observation and control of an individual knowledgeable of, and empowered to implement, required access and exposure control measures.
- (b) The following areas may be excepted from the radioactive material area posting requirement of §835.603(g) when:
  - (1) Posted in accordance with §835.603(a) through (f);  
or



- (2) Each item or container of radioactive material is labeled in accordance with requirements in 10 CFR 835 such that individuals entering the area are made aware of the hazard; or
  - (3) The radioactive material of concern consists solely of structures or installed components which have been activated (i.e., such as by being exposed to neutron radiation or particles produced by an accelerator).
- (c) Areas containing only packages received from radioactive material transportation need not be posted in accordance §835.603 until the packages are monitored in accordance with §835.405.
3. In addition, storage rooms or cabinets containing radioactive sources should meet the following requirements:
- a. Locked and posted
  - b. Located to minimize damage from fire
  - c. Free of flammable substances
  - d. Isolated from occupied areas or located in radiological areas or radiological buffer areas
  - e. When selected in continuously occupied controlled areas, the radiation level at the closest approach is as low as reasonably achievable and does not exceed 0.5 millirem per hour on average

#### F. SOURCE DISPOSAL

Obsolete, excess, or leaking accountable sealed radioactive sources should be disposed of according to RCO instructions.

**III. SUMMARY**

- A. Review major points
  - 1. Requirements
  - 2. Control of sources
  - 3. Receipt
  - 4. Radioactive Materials Storage Areas
  - 5. Inventory and transfer
  - 6. Surveys
  - 7. Leak test
  - 8. Source disposal
- B. Review learning objectives

**IV. EVALUATION**

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.

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**Course Title:** Radiological Control Technician  
**Module Title:** Environmental Monitoring  
**Module Number:** 2.09

**Objectives:**

- 2.09.01 State the goals of an environmental monitoring program.
- 2.09.02 State the exposure limits to the general public as they apply to environmental monitoring.
- 2.09.03 Define the term "critical nuclide."
- 2.09.04 Define the term "critical pathway."
- 2.09.05 State locations frequently surveyed for radiological contamination at outdoor waste sites associated with your site and the reasons for each.
- 2.09.06 Define the term "suspect waste site," and how they can be identified.
- 2.09.07 Describe the methods used for environmental monitoring at your site.

**References:**

1. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5<sup>th</sup> ed.; Pacific Radiation Corporation; 2008.
2. NCRP Report #50, "Environmental Radiation Measurements," (1976).
3. DOE Order 5400.5.
4. 40 CFR 61.
5. 40 CFR 141 (Safe Drinking Water Act).
6. 40 CFR 191.

**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

Environmental monitoring plays a large role in the field of radiological control. Environmental monitoring is used to estimate human population doses, determine the impact a site has on the environment, monitor for unplanned releases as well as quantifying planned releases, and gives us data useful in determining pathway data.

## C. Overview of Lesson

1. Environmental monitoring goals
2. Principles of program design
3. Radiological control responsibilities
4. Analysis of environmental samples
5. Site environmental monitoring methods
6. Transport mechanisms

## D. Introduce learning objectives

O.H.: Objectives

**II. MODULE OUTLINE**

## A. GOALS OF ENVIRONMENTAL MONITORING PROGRAMS

Objective 2.09.01

1. Estimate Human Population Doses
  - a. ALARA dictates that we must be aware of changes in radiation exposure to the general population which results from nuclear operations

- b. Issuing TLDs to population is not practical. In addition the TLDs are not sensitive enough to detect changes in environmental radiation levels
  - c. The only practical way to determine population exposure is by measurement of environmental radiation levels:
    - 1) External radiation level
    - 2) Radioactivity present in air
    - 3) Radioactivity present in food
    - 4) Radioactivity present in water
  - d. Population exposure can then be determined by using these values combined with a knowledge of the drinking water sources and the types of food consumed in the region
2. Determine Site Impact
- a. Environmental levels are determined prior to beginning site operations. A pre-operational survey (or characterization) is required for a minimum of 1 year, and preferably 2 years, prior to the startup of any new site or waste site
  - b. Environmental levels are then measured during site operation and changes are tracked to determine site impact
  - c. The exposure of members of the public, outside of controlled areas, to radiation sources as a consequence of all routine DOE activities shall not cause, in a year, an effective dose equivalent greater than 100 mrem (1 mSv). The 100 mrem effective dose equivalent in a year is the sum of the effective dose equivalent from exposures to radiation sources external to the body during the year plus the committed effective dose equivalent from radionuclides taken into the body during the year.

Note: Refer to Module 2.04 for discussion of equivalencies in the dosimetric terms between ICRP 26/30 and 60/68 and limits for members of the public inside controlled areas.

#### Objective 2.09.02

The DOE primary standard of 100 mrem to members of the public in a year is lower than the previous primary limit of 500 mrem. The lower value was selected in recognition of the ICRP recommendation to limit the long-term average effective dose equivalent to 100 mrem per year, or less.

Experience suggests that the lower dose is readily achievable for normal operations of DOE facilities.

- d. A higher dose limit, not to exceed the 500 mrem effective dose equivalent recommended by the ICRP as an occasional annual limit, may be authorized for a limited period if it is justified by unusual operating conditions.
  - e. For airborne emissions from all DOE sources of radionuclides, the exposure of members of the public to radioactive materials released to the atmosphere as a consequence of routine DOE activities shall not cause members of the public to receive, in a year, an effective dose equivalent greater than 10 mrem.
  - f. For exposure from sources from the management and storage of spent nuclear fuel, high-level, and transuranic wastes at disposal facilities, the exposure of members of the public to direct radiation or radioactive material released shall not cause members of the public to receive, in a year, a dose equivalent greater than 25 mrem to the whole body or a committed dose equivalent greater than 75 mrem to any organ.
  - g. For the drinking water pathway, it is the policy of DOE to provide a level of protection for persons consuming water from a public drinking water supply operated by the DOE that is equivalent to that provided to the public by the public community drinking water standards of 40 CFR 141. These systems shall not cause persons consuming the water to receive an effective dose equivalent greater than 4 mrem in a year.
3. Detect and Quantify an Unplanned Release
- a. Although adequate Radiation Safety programs are maintained at all licensed sites, there is always the possibility of an "unknown release."
  - b. Environmental monitoring can serve as a secondary backup system to the primary defense of a good Radiation Safety program
    - 1) Windscale reactor fire in 1957 detected by I-131 detected downwind of the site
    - 2) Chernobyl detected by the Western powers through environmental monitoring programs in Europe

4. Meet Legal or Regulatory Requirements
  - a. DOE regulations dictate environmental monitoring requirements for that site
  - b. Larger facilities and plants are required to maintain continuous, extensive monitoring programs according to DOE requirements, Federal and State regulations, and regulatory guides
  - c. Monitor all inactive, existing, and new low-level waste (LLW) disposal sites to assess both radiological and nonradiological hazards (DOE Order 5820.2A)
  - d. Monitor and maintain all surplus facilities prior to decontaminating or decommissioning (DOE Order 5820.2)
5. Create and Maintain a Good Public Image
  - a. Operating an environmental monitoring program more extensively than required by law shows the site to be a "good neighbor"
  - b. Extensive environmental monitoring also provides added protection against lawsuits
6. Obtaining Pathway Data Objective 2.09.03
  - a. A critical nuclide is one of a group of nuclides which cause the largest dose contribution to the actual population at risk near the site. Typical operational reactor "critical nuclides" include: Objective 2.09.04
    - 1) Actinium-227
    - 2) Barium/Lanthanum-140
    - 3) Cesium-137
    - 4) Cobalt-60
    - 5) Hydrogen-3 (Tritium)
    - 6) Iodine-131
    - 7) Manganese-54



- 8) Plutonium-238
  - 9) Plutonium-239
  - 10) Radium-226
  - 11) Strontium-89
  - 12) Strontium-90
  - 13) Thorium-230
  - 14) Thorium-232
- b. A "pathway" is any route that radioactivity can follow in passing from a licensee to a person in the general population where it becomes internally deposited or contributes external dose
  - c. A critical pathway is the route taken, from the point of release to body entry, of a critical radionuclide which causes human exposure
  - d. Environmental monitoring enables pathway data to be collected and analyzed. This can help verify or reject theoretical "transport mechanism" data used in determining population exposure
7. Test Adequacy of Radiological Control Measures
- a. Small amounts of non-routine radionuclides beginning to show up in the environmental samples could indicate problems at the site
  - b. Radiological Controls and operations at the site can then be reviewed prior to any releases above the prescribed limits
8. Study of Air and Water Mixing Patterns
- a. To aid in the study of transport mechanisms, small amounts of radioisotopes are sometimes released under controlled conditions to determine air and water pathways
  - b. This data is used in determining population dose estimates
9. "Non-Industry" Applications
- a. Atmospheric and oceanic circulation studies

- b. Monitoring of redistribution of radioactivity due to man's use of radioactive materials, and man's extensive modification of the earth's surface. Redistribution of naturally-occurring radionuclides in the environment can cause significant changes in the background radiation levels in an area. Changes are made by:
  - 1) bringing in topsoil from other areas
  - 2) the use of fertilizers
  - 3) plowing the ground
  - 4) the addition of water to the ground
    - a) can serve to attenuate radiation
    - b) may also introduce new radionuclides
  - 5) the presence of structures
    - a) attenuate radiation
    - b) may also introduce new radionuclides
  - 6) industrial activities
    - a) can emit naturally occurring radionuclides to the air or water
  - 7) there are many other changes that individuals make

## B. PRINCIPLES OF PROGRAM DESIGN

In order to meet regulatory requirements, environmental monitoring programs must be operated at DOE facilities. One of the main reasons to operate an environmental monitoring program is to determine what increases in radioactivity in the environment is due to the operation of the site.

### 1. Pre-operational Program Design

Prior to operating a site, an environmental monitoring program will be run in order to:

- a. Locate Radiation Anomalies

This information helps to identify critical nuclides and critical pathways for the new site.

- b. Document Ambient Levels
  - c. Identify Critical Pathways/Nuclides
  - d. Document Meteorology Patterns
2. Post-operational Program Design

Another phase of environmental monitoring is entered once the site begins operations. Measurements are now made to aid in dose assessment, for the determination of compliance with allowed releases, and for the identification of any changes in radioactivity in the environment due to the operation of the site. In order to accomplish these goals, we need:

- a. A monitoring program with enough sensitivity to detect environmental changes in radioactivity.
- b. A monitoring program with enough selectivity to be able to separate nuclides of interest from background interference.

The post-operational program is commonly on a smaller scale than the pre-operational program. Due to the extensive monitoring done prior to start of operations, attention to the post-operational program can be focused primarily on the critical nuclides, and the instrumentation on the critical pathways.

### C. RADIOLOGICAL CONTROL RESPONSIBILITIES

- 1. Radiological Surveys are conducted to monitor radioactive contamination
  - a. General Monitoring Requirements:
    - 1) Ambient air in the immediate vicinity of active and inactive sites
    - 2) Surface water (rivers, estuaries, lakes and oceans) and sediments are monitored for constituents indicating the status of operational practices and control
    - 3) Soil and vegetation are monitored to detect possible contamination from fallout and uptake.
    - 4) Ground water wells are surveyed to ensure their physical integrity

- 5) Background dose rates are monitored near facilities that may have elevated dose rates
  - 6) Radiation surveys are performed to detect contamination spread
2. Survey frequencies for particular sites are to be determined by the technical judgement of Environmental Protection and/or Radiological Control and may depend on the site history, radiological status, use and general conditions.
  3. Appropriate documentation must be completed for each environmental survey.
  4. Radiological Surveys: Objective 2.09.05  
*(Insert site specific information here.)*
    - a. Soil
    - b. Water
    - c. Air
  5. Suspect Waste Site Investigations Objective 2.09.06
    - a. A suspect waste site is any site that is thought for any reason to contain dangerous waste, hazardous waste and/or radioactive waste. This does not include sites already identified
  6. Suspect waste site identification
    - a. Any employee having any reason to believe that a site contains dangerous waste, hazardous waste, and/or radioactive waste should report this information to management.
    - b. The following conditions should be looked for:
      - 1) Soil discoloration is present
      - 2) An unusual soil depression or disturbance exists
      - 3) Pipes emerging from the ground (indicates a possible crib, tank or other structure)
      - 4) Plant stress

- 5) The unusual absence of plant life
- 6) Vaults, chambers, concrete or steel structures, drums, pipes, or munitions protruding from the surface of a disturbed area
- 7) Holes, sinkholes, or collapsed structures (indicates the presence of man-made structures or voids beneath the surface)
- 8) The presence of hazardous and/or radioactive material in soil samples
- 9) Documentation or personnel interviews which indicate the past existence of a waste disposal site

#### D. ANALYSIS OF ENVIRONMENTAL SAMPLES

1. Environmental sample types include:
  - a. Air samples
  - b. Soil samples
  - c. Vegetation samples
  - d. Animal samples
  - e. Surface water samples
  - f. Groundwater samples
  - g. Background radiation
  - h. Radiation surveys.
2. Methods of Monitoring
  - a. Environmental levels of external gamma radiation are measured using film or thermoluminescent dosimeters
    - 1) The lower detection level for film badges is approximately 10 mrem/month
    - 2) The lower detection level for TLDs is approximately 1 mrem/month. Corrections must be made, however, for fading of dosimeters, and energy dependence

- b. Activity deposited on the ground (or "fallout") is isotopically analyzed and quantified to determine release point of origin and amount released. Generally, gas-flow proportional counters are used for gross alpha and beta determinations. Gamma spectrum are obtained using Germanium semiconductor systems. Alpha spectroscopy can also be used to isotopically analyze and quantify environmental samples
  - 1) Fallout simply means radioactive particles that settle out onto the ground. The term does not necessarily imply a nuclear detonation has occurred
  - 2) "Flypaper" technique is used, which consists of an adhesive covered piece of waterproof paper, which is positioned in the environment to catch and hold particulate matter which settles out. This technique traps approximately 70% of the particles that fall on it
  - 3) Rain water is also collected and analyzed for radioactivity that may have been washed from the air
  - 4) Grass and other broadleaf vegetation is also a good collection media for "fallout." (Note how this may be part of a critical pathway, e.g., cows graze on contaminated pastures, and the general population drinks the now contaminated milk)
- c. Atmospheric sampling is accomplished by drawing air through a filter at a known rate and then counting the filter for particulate activity
  - 1) Air sampling for particulates
    - a) Inertial separation is one method for radioactive particulate air sampling. It is especially effective in determining the size distribution of particles. This information is necessary for internal dose assessment following inhalation of particulate radionuclides. A Cascade Impactor is an example of a sampler utilizing the inertial separation method

- b) Filtration is another method for radioactive particulate air sampling. This consists simply of a pump which pulls air through a filter matrix. The filter is then removed and counted to determine airborne radioactive particulate concentrations
  - (1) Dust loading is a factor in collection efficiency. As the filter becomes plugged up with dust, air flow generally decreases, but the collection efficiency usually increases
  - (2) The rate at which air (particles) is drawn through the filter also is a factor in collection efficiency.
    - (a) At low rates of air flow, efficiency is relatively high due to diffusion of particles in the filter media. In other words, the air particles "drift" through the filter media, and become trapped in the dead air spaces in the filter
    - (b) At high rates of air flow, efficiency is also relatively high due to the phenomena of impaction. This is an increased collection of particles due to the higher speed of the particles causing them to "crash" into the filter media, and bury themselves in the fibers of the filter. It is necessary to realize, however, that for gross beta and especially gross alpha counting, this method will introduce more self-shielding in the counting process
- 2) Air sampling for gases
  - a) Continuous flow sampling for radioactive gases is a common method of air concentration determination. Air is pumped or exhausted through a chamber housing a detector. The detector, coupled with an air flow-rate meter, can give real-time determination of airborne radioactivity concentration. An example of a system utilizing this method is a Stack Monitor.

- b) Grab sampling is another method of measuring air activity concentration. This method uses an evacuated chamber which is opened in the environment to be sampled, then re-sealed. The inside surfaces of the chamber are coated with a scintillation phosphor, such that when different types of radiation interact with the phosphor, small flashes of light are produced. When the chamber is placed in a light-tight housing with a photomultiplier tube, these flashes of light are measured and are indicative of the activity concentration in the grab cell. Another type of grab sampler is an evacuated tube or chamber with a thin-walled G-M tube mounted along its central axis. For analysis, then, the G-M is connected to a scaler, and a gross count is made
  - c) Adsorption is the assimilation of gas, vapor or dissolved matter by the surface of a solid or liquid (the adsorbent). Gaseous air activity concentration is measured by drawing the air to be measured through the adsorbent, and then counting the adsorbent. Common adsorbents are activated charcoal, silver zeolite (AgZ), and silica gel
  - d) Condensation is used in monitoring for airborne tritium activity. Water vapor in the air which may contain tritium components are condensed by using a super-cooled strip of metal in the ambient air. Water vapor will condense and freeze on this strip. The ice is then melted, and a liquid scintillation counter is then used to count for tritium.
- d. Aquatic samples may include sediments, bottom organisms, vegetation, fin fish, or shell fish. Water needs to be analyzed only if it is used for consumption or irrigation. In most cases, samples of shell fish and fin fish are saved to document the principal route of human exposure. If waste is being discharged into a flowing stream of potable water, a continuous sampler should be used.
- e. Food sampling is not necessary if proper regulations are followed that restrict the discharge of liquid and solid radioactive effluents (other than that which is desirable for good relationships with the public). The type of sampling will be determined by the isotope released.



- 1) Radionuclides such as Co-60 and Zn-65 concentrate in shellfish. Sampling should be done if these radioactive fission products are discharged into an estuary populated with shellfish.
- 2) If I-131 is released, cow pastures should be sampled as well as the milk produced. I-131 will appear in milk within 24 hours.

## E. SITE ENVIRONMENTAL MONITORING METHODS

Objective 2.09.07

*(Insert site specific information here.)*

## F. TRANSPORT MECHANISMS

## 1. Atmospheric Transport

- a. Airborne radioactive contaminants are carried downwind and dispersed by normal atmospheric mixing processes
- b. Internal irradiation occurs if the radionuclides are inhaled and incorporated in the body
- c. External irradiation occurs by beta and gamma irradiation from the plume
- d. Material is removed from the plume by impaction of the plume with the ground surface or by washout due to rain
- e. Deposition of the material from the plume leads to further exposure pathways through:
  - 1) Direct external exposure from contaminated surfaces
  - 2) Inhalation of re-suspended material
  - 3) Ingestion of contaminated foodstuffs
- f. Factors considered in determining the deposition of radioactive material back to earth include:
  - 1) Wind speed
  - 2) Temperature
  - 3) Stack height
  - 4) Particle size

## 5) Weather conditions

- g. A reverse in the normal upward movement of hot air can slow down the dilution of radioactive release. The condition where hot air develops over cooler air is called a temperature inversion. A temperature inversion can occur when:
  - 1) A warm front covers a cooler earth
  - 2) A cool front is injected under warm air (sea breeze)
  - 3) The normal cycle of a summer day when the earth cools off faster than the air above

## 2. Surface Water Transport

- a. Liquid effluents may be discharged into various types of surface water bodies:
  - 1) Rivers
  - 2) Estuaries
  - 3) Lakes
  - 4) Oceans
- b. In rivers, the rate of transport is slower than in the atmosphere
- c. Radionuclides may be absorbed by bottom sediments, and may accumulate in the aquatic biota
- d. Although these two processes involve only a small fraction of the inventory, they may be significant with respect to radiation exposure
- e. Radioactive materials released in rivers eventually feed into the ocean
  - 1) In the ocean surface layer (75 m in depth and located above the thermocline) the mixing time is 3-5 years
  - 2) Below the thermocline in the deep ocean, the mixing is much slower
- f. Some aquatic mixing factors include
  - 1) Depth of water

- 2) Type of bottom
  - 3) Shoreline configuration
  - 4) Tidal factors
  - 5) Wind
  - 6) Temperature
  - 7) Salinity
  - 8) Solubility of radioactive material
  - 9) Depth at which pollutant is introduced
3. Movement in the Ground
- a. Radionuclide movement in the ground is generally the slowest
  - b. Movement of most radionuclides depends upon convective transport in water
  - c. In humid regions the rate of ground water movement near the surface is on the order of 1 ft/day. In arid areas, the rate is much slower
  - d. There is an abundance of solid material for absorption of radionuclides and interaction with this geologic media can reduce the rate of radionuclide movement to a small fraction of underground water movement

### III. SUMMARY

- A. Review major topics
1. Environmental monitoring goals
  2. Principles of program design
  3. Radiological control responsibilities
  4. Analysis of environmental samples
  5. Site environmental monitoring methods
  6. Transport mechanisms
- B. Review learning objectives

**IV. EVALUATION**

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.

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**Course Title:** Radiological Control Technician  
**Module Title:** Access Control and Work Area Setup  
**Module Number:** 2.10

**Objectives:**

- 2.10.01 State the purpose of and information found on a Radiological Work Permit (RWP) including the different classifications at your site.
- 2.10.02 State responsibilities in using or initiating a RWP.
- 2.10.03 State the document that governs the ALARA program at your site.
- 2.10.04 Describe how exposure/performance goals are established at your site.
- 2.10.05 State the conditions under which a pre-job ALARA review is required at your site.
- 2.10.06 State the conditions under which a post-job ALARA review is required at your site.
- 2.10.07 State purpose of radiological postings, signs, labels, and barricades; and the RCTs responsibilities for them.
- 2.10.08 Identify the following radiological postings at your site, requirements for posting/barriers, and requirements for entry:
  - a. Radiological Buffer Area
  - b. Radiation Area
  - c. High Radiation Area
  - d. Very High Radiation Area
  - e. Hot Spot
  - f. Contamination Area
  - g. High Contamination Area
  - h. Airborne Radioactivity Area
  - i. Fixed Surface Contamination
  - j. Soil Contamination
  - k. Radioactive Material Area
  - l. Underground Radioactive Material Area
- 2.10.09 Describe good practices, support equipment to use, and common discrepancies in setting up radiological areas.
- 2.10.10 List discrepancies frequently observed in containment devices.
- 2.10.11 Describe good practices in setting up portable ventilation systems and count rate meters.
- 2.10.12 List the requirements individuals should follow while working in RBAs.
- 2.10.13 State the requirements for removing or releasing materials from any radiological area.

**References:**

1. 10 CFR 835, "Occupational Radiation Protection" (2007).
2. DOE Radiological Control Standard, 2008.

**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

This lesson presents instruction in Radiological Work Permits, various types of postings used in radiological areas, setting up radiological areas, access controls, and releasing of material from radiological areas. All of these are fundamental duties of RCTs.

## C. Overview of Lesson

1. General Overview - Area setup and access control
2. Points of importance
  - a. RWPs
  - b. Radiological postings
  - c. Setting up radiological areas
  - d. Good practices and discrepancies commonly observed in setup of various portions of radiological areas.
  - e. Access control
  - f. Removing materials from radiological areas

## D. Introduce Objectives

O.H.: Objectives

**II. MODULE OUTLINE**

## A. RADIOLOGICAL WORK PERMITS (RWPs)

See DOE RCS Art.  
321-323*(Insert site specific information here)*

Objective 2.10.01



1. Structure of an RWP
  - a. Description of work
  - b. Work area/process radiological controls
  - c. Dosimetry requirements
  - d. Pre-job briefing requirements, as applicable
  - e. Training requirements for entry
  - f. Protective clothing and respiratory protection requirements
  - g. Radiological control coverage requirements and stay time controls, as applicable
  - h. Limiting radiological conditions that may void the RWP
  - i. Special dose or contamination reduction considerations
  - j. Special personnel frisking considerations
  - k. Technical work document number, as applicable
  - l. Unique identifying number
  - m. Date of issue and expiration
  - n. Authorizing signature
2. RWPs should be used to control the following activities:
  - a. Entry into High and Very High Radiation Areas
  - b. Entry into High Contamination Areas
  - c. Entry into Airborne Radioactivity Areas
3. RWPs should be used to control the following activities:
  - a. Entry into Radiation Areas
  - b. Entry into Contamination Areas
  - c. Handling of materials with removable contamination that exceeds the values in Table 2-2 of the Radiological Control Standard

4. Responsibilities when using an RWP
  - a. It is important for individuals to comply with the requirements of the RWP to prevent personnel contamination or unnecessary radiation exposure.

*(Insert site specific information here)*

B. ALARA CONSIDERATIONS FOR ACCESS CONTROL AND WORK AREA SETUP Objective 2.10.02

1. ALARA documentation

*(Insert site specific information here)*

2. Exposure/performance goals

Objective 2.10.03

*(Insert site specific information here)*

See DOE RCS Art. 131-133 (or appropriate site document)

3. Pre-job ALARA Reviews

- a. At a minimum, the pre-job briefing should include:

Objective 2.10.04

1. Scope of work to be performed
2. Radiological conditions of the workplace
3. Procedural and RWP requirements
4. Special radiological control requirements
5. Radiologically limiting conditions, such as contamination or radiation levels that may void the RWP
6. Radiological Control Hold Points
7. Communications and coordination with other groups
8. Provisions for housekeeping and final cleanup
9. Emergency response provisions

DOE RCS Art. 324.2

- b. Pre-job ALARA review requirements

Objective 2.10.05

*(Insert site specific information here)*

## 4. Post-job ALARA Reviews

- a. Post-job meetings allow the opportunity to critique the work performance. Although, they will not affect the dose already received for a particular job, they can be effective in reducing the doses received the next time that job is performed.
- b. Information discussed at post-job meetings includes discussions of what went wrong and what could have been done differently to reduce the exposures received.
- c. Post-job meetings rely heavily on the input of each radiation worker for information on how best to reduce exposure the next time that job is performed.
- d. Typical questions asked could include:
  - 1) Were there any problems performing the job in accordance with the procedure?
  - 2) Did you have the tools and equipment needed to perform the work? Could special tools ease the job?
  - 3) Were there any unexpected conditions noted during the work? Could these conditions have been anticipated?
  - 4) Were there any unexpected delays in the performance of the job? What was the cause of the delay?
  - 5) Was temporary shielding used? Could the use of temporary shielding reduce exposures received for this job?
  - 6) What tools or work practices worked well that need to be reused?

## e. Post-job ALARA Review Requirements

Objective 2.10.06

*(Insert site specific information here)*

## C. RADIOLOGICAL POSTINGS

Objective 2.10.07

## 1. Purpose of radiological postings, signs and labels is to:

- a. Identify items or areas that have the potential for, or actually contain, radiological hazards.

- b. Identify the radiological hazard(s) present in an area (e.g. Radiation Area, Airborne Radioactivity area, Radiography Area).
- c. And to prevent:
  - 1) Workers from inadvertently entering radiologically controlled area(s), and/or
  - 2) Mishandling radioactive materials.
- 2. Each individual is responsible to read and comply with all the information identified on radiological postings, signs and labels.
- 3. Since there may be more than one radiological hazard identified on a posting, sign or label, it is important to read all of the information and not just the first line.
- 4. All access points into an area must be posted to ensure workers are adequately warned of the hazards in the area.
- 5. Postings and status boards (if applicable) should be promptly updated after completion of a survey to reflect the corrected conditions in the area.
- 6. If necessary the RWP should be amended to reflect any changes in the area.
- 7. The information on status boards, RWPs, posting and survey maps should be consistent. If there is a discrepancy it should be immediately corrected. Workers could review erroneous data that has not been updated and subsequently become contaminated or receive some unnecessary radiation exposure.
  - a. Radiological Control Technicians should immediately update postings after performing a survey. The RWP and any status boards must also be updated.
  - b. If the posting was updated and the RWP was not, a worker may consider the RWP correct and the posting wrong.
  - c. If a worker entered the area based on the incorrect RWP information he could become contaminated or receive some unnecessary radiation exposure.
- 8. Areas should be posted if there is a strong potential for the situation to exist, even if it is not now present.

- a. Areas can be posted as Airborne Radioactivity Areas or Surface Contamination Areas, if equipment in the area has been known to leak and create airborne or contamination hazards. Posting areas in such a situation will ensure that the proper protective equipment is used and could prevent a personnel contamination incident or a case of internal exposure.
  - b. If areas are posted only when the appropriate limits have been reached, personnel can be subjected to hazards when the hazard could have otherwise been minimized.
9. Disregarding any radiological posting, sign or label can lead to unnecessary or excessive radiation exposure and/or personnel contamination.
  10. Unauthorized removal or relocation of radiological postings, signs and labels may lead to disciplinary actions up to and including job termination.
  11. If any type of material used to identify radiological hazards is found outside a RBA, it should be reported to radiological control personnel immediately. RCT shall perform a survey of the sign, posting or label and conduct a survey of the area in which it was found.
    - a. Any contamination or higher than expected radiation levels must be promptly reported to the RCT supervisor.

#### D. TYPE OF RADIOLOGICAL POSTINGS, SIGNS AND LABELS

Objective 2.10.08

10 CFR 835 requires the following for posting and labeling:

1. §835.601 General Requirements
  - (a) Except as otherwise provided in this subpart, postings and labels required by this subpart shall include the standard radiation warning trefoil in black or magenta imposed upon a yellow background.
  - (b) Signs required by this subpart shall be clearly and conspicuously posted and may include radiological protection instructions.
  - (c) The posting and labeling requirements in this subpart may be modified to reflect the special considerations of DOE activities conducted at private residences or businesses. Such modifications shall provide the same level of protection to individuals as the existing provisions in this subpart.

NOTE: See also §835.605

## 2. §835.602 Controlled areas

- (a) Each access point to a controlled area (as defined in §835.2) shall be posted whenever radiological areas exist in the area. Individuals who enter only the controlled area without entering radiological areas are not expected to receive a total effective dose of more than 100 mrem (0.001 sievert) in a year.
- (b) Signs used for this purpose may be selected by the contractor to avoid conflict with local security requirements.

## 3. §835.603 Radiological areas

Each access point to a radiological area (as defined in §835.2) shall be posted with conspicuous signs bearing the wording provided in this section.

- (a) Radiation Area - any area, accessible to individuals, in which radiation levels could result in an individual receiving an equivalent dose to the whole body in excess of 0.005 rem (0.05 millisievert) in 1 hour at 30 centimeters from the source or from any surface that the radiation penetrates.

The words “Caution, Radiation Area” shall be posted at each radiation area.

- (b) High Radiation Area - any area, accessible to individuals, in which radiation levels could result in an individual receiving an equivalent dose to the whole body in excess of 0.1 rem (0.001 sievert) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

The words, “Caution, High Radiation Area” or “Danger, High Radiation Area shall be posted at each high radiation area.

- (c) Very High Radiation Area - any area, accessible to individuals, in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rads (5 grays) in one hour at 1 meter from a radiation source or from any surface that the radiation penetrates. The words “Grave Danger, Very High Radiation Area” shall be posted at each very high radiation area.

- (d) Airborne Radioactivity Area - any area, accessible to individuals, where (1) the concentration of airborne radioactivity, above natural background, exceeds or is likely to exceed the DAC values listed in Appendix A or Appendix C of 10 CFR 835; or (2) an individual present in an area without respiratory protection could receive an intake exceeding 12 DAC-hours in a week.

The words “Caution, Airborne Radioactivity Area” or “Danger, Airborne Radioactivity Area” shall be posted at each airborne radioactivity area.

- (e) Contamination Area means any area, accessible to individuals, where removable surface contamination levels exceed or are likely to exceed the removable surface contamination values specified in Appendix D of this Part 835, but do not exceed 100 times those values. The words “Caution, Contamination Area” shall be posted at each contamination area.
  - (f) High Contamination Area means any area, accessible to individuals, where removable surface contamination levels exceed or are likely to exceed 100 times the removable surface contamination values specified in appendix D of Part 835. The words “Caution, High Contamination Area” or “Danger, High Contamination Area” shall be posted at each high contamination area.
  - (g) Radioactive Material Area means any area within a controlled area, accessible to individuals, in which items or containers of radioactive material exist and the total activity of radioactive material exceeds the applicable values provided in appendix E of Part 835. The words “Caution, Radioactive Material(s)” shall be posted at each radioactive material area.
4. §835.604 Exceptions to posting requirements
- (a) Areas may be excepted from the posting requirements of §835.603 for periods of less than 8 continuous hours when placed under continuous observation and control of an individual knowledgeable of, and empowered to implement, required access and exposure control measures.
  - (b) The following areas may be excepted from the radioactive material area posting requirements of §835.603(g):
    - (1) Areas posted in accordance with 835.603(a) through (f); and
    - (2) Areas in which each item or container of radioactive material is clearly and adequately labeled in accordance with §§835.605 and 835.606 such that individuals entering the area are made aware of the hazard.
  - (c) Areas containing only packages received from radioactive material transportation need not be posted in accordance with §835.603 until the packages are surveyed in accordance with §835.405.

- |   |   |
|---|---|
| <p>5. Area designations</p> <p><i>(Insert site specific information here)</i></p> <p>6. Requirements for posting/barriers</p> <p><i>(Insert site specific information here)</i></p> <p>3. Requirements for entry</p> <p><i>(Insert site specific information here)</i></p>  | <p>Review 10 CFR 835 definitions of areas.</p> <p>See 10 CFR 835</p>  |
| <p>E. SETTING UP RADIOLOGICAL AREAS</p>   |   |
| <p>1. Good practices to be considered whenever possible in setting up Radiological Areas.</p> <p>a. Establish walkways in low dose areas.</p> <p>b. Do not store radioactive materials near walkways or where personnel frequently work.</p> <p>c. Place rope boundaries as close to the source of contamination as possible to minimize the size of the contaminated area. Care must be taken to ensure the area is not so limited that contamination is easily spread across the boundaries.</p> <p>d. Use appropriate containment devices to prevent the spread of contamination.</p> <p>e. Establish laydown areas for equipment to limit personnel safety hazards and/or radiation exposure.</p> <p>f. Set up SOPs upwind of contamination hazards.</p> <p>g. Post all accessible sides and entrance(s) to areas containing radiological hazards.</p> <p>h. Use Personnel Contamination monitors along with portable contamination survey instrumentation whenever possible. PCMs are more likely to detect contamination on individuals because personnel tend to survey too quickly.</p> | <p>NOTE: RMA posting and labeling of radioactive material was covered in Module 2.08. Objective 2.10.09</p> <p>If this happened with an actual contamination incident the employee surveying quickly could subsequently pass over the contamination areas with the portable contamination survey instrumentation.</p> |



2. The following are commonly observed discrepancies that should be avoided in the setup of Radiological Areas.
  - a. Posting information not updated or information otherwise incorrect.
  - b. Boundaries not verified for contamination, radiation, and airborne radioactivity hazards.
  - c. Survey instruments out of calibration or defective.
  - d. Step-off-pads not set up for efficient removal of protective clothing. (Not enough room to prevent contaminating the SOPs.)
  - e. Laundry and waste receptacles not placed for efficient use or not placed at all. Receptacles not properly labeled as to their contents.
  - f. Boundaries of areas setup too far from the hazards interfering with access to areas otherwise unaffected.
  - g. Portable contamination survey instruments not located close to the step-off-pads.
  - h. Status boards do not reflect where SOPs and boundaries lie.
  - i. Status board not kept up-to-date. The information on status boards, postings and RWPs should agree.
  - j. Tripping hazards exist from wires, hoses, or cables.
  - k. Background radiation in monitoring area too high for efficient detection of low level contamination.
  - l. Instrumentation not set up for proper operation.
  - m. Protective clothing (gloves and booties) not readily available in a personnel contamination event.
  - n. Phone or other communication devices not available near the SOP or portable contamination survey instruments.
  - o. Not posting all accesses to the area.
  - p. Failure to post dress and undress procedures.
3. Since contamination or airborne radioactivity and radiation levels are subject to change, it is essential to be able to quickly establish a Radiological Area. To properly set up a Radiological Area, the following support equipment should be readily available.

4. Containment devices include glove boxes, glove ports, hot cells, huts, and windbreaks. Common discrepancies observed in containment devices include. Objective 2.10.10
- a. Holes/leaks in the containments, facilitating the spread of contamination.
  - b. Liquids accumulating in hoses or main portions of the containment.
  - c. Airlocks too small to remove protective clothing without spreading contamination.
  - d. Ventilation exhaust not directed to the plant ventilation system.
  - e. Material allowed to accumulate inside containments, limiting safe and/or efficient use.
  - f. Sharp objects used inside containments (not covered or taped).
  - g. Devices not tethered to prevent introduction into systems.
  - h. Transfer sleeves/ports are not used or are unavailable.
  - i. Containment not provided with a HEPA filter or ventilation exhaust.
  - j. Containments not periodically surveyed inside and out.
  - k. No means of quickly verifying loss of ventilation.
  - l. Containment not decontaminated prior to dismantling.
  - m. Adequate access not provided for lines or hoses.
  - n. Containment not maintained at a negative pressure.
  - o. Containment not supported properly to minimize stress from minor ventilation changes or not structurally supported to maintain its configuration during use.
  - p. Containments not inspected prior to use and periodically during use.
  - q. Not using appropriate containment devices for leaks.
  - r. Not using a funnel to collect leakage, if appropriate.
  - s. Plastic components showing fatigue or wear.

- t. Funnel not positioned to collect all leaking fluid, if appropriate.
  - u. Drain lines kinked allowing the buildup of liquids.
  - v. Drain lines not secured properly to the collection device.
  - w. Containment device not labeled to indicate hazards that are present.
5. Portable ventilation systems are frequently used to remove contaminated air or filter contamination in the air. Radiological control personnel should adhere to the following good practices in setting up portable ventilation systems. Objective 2.10.11
- a. Use only HEPA (High Efficiency Particulate Air) filters with pre-filters (roughing filters).
  - b. Perform radiation survey on filters periodically while in use.
  - c. Have radiological limits established for filter replacement.
  - d. Exhaust filter discharge to the plant ventilation system whenever possible.
  - e. Ensure that there are no openings in the trunk or between the blower and the filter.
  - f. Monitor the filter differential pressure (d/p) periodically.
  - g. Establish filter D/P at which the filter must be replaced.
  - h. Remove filters into plastic bags to prevent the release of activity.
  - i. Position streamers to signify the flow of ventilation through doorways or through containment devices.
6. The proper setup and use of portable contamination survey instruments and Personnel Contamination Monitors (PCMs) can ensure that contamination is more likely to be detected on workers. The following is a list of good practices for setting up portable contamination survey instrumentation and PCMs.
- a. They must be placed in low background area.
  - b. They need reliable power supply.
  - c. They should be positioned to facilitate easy access by workers.
  - d. Alarms should be set according to site administrative control levels or DOE limits.

- e. Must ensure instrument is source checked and calibrated.
- f. Extension cords must be checked for electrical safety.
- g. Portable contamination survey instruments and PCMs should be placed upwind of contaminated areas.
- h. They should not be placed near radioactive material storage areas or other areas where the background radiation can change.
- i. Portable contamination survey instruments should have sources provided to source check the instrument.

#### F. ACCESS CONTROL

Review 10 CFR 835 definitions

10 CFR 835 requires the following:

##### 1. §835.501 Radiological Areas

- (a) Personnel entry control shall be maintained for each radiological area.
- (b) The degree of control shall be commensurate with existing and potential radiological hazards within the area.
- (c) One or more of the following methods shall be used to ensure control:
  - (1) Signs and barricades;
  - (2) Control devices on entrances;
  - (3) Conspicuous visual and/or audible alarms;
  - (4) Locked entrance ways; or
  - (5) Administrative controls.
- (d) Written authorizations shall be required to control entry into and perform work within radiological areas. These authorizations shall specify radiation protection measures commensurate with the existing and potential hazards.
- (e) No control(s) shall be installed at any radiological area exit that would prevent rapid evacuation of personnel under emergency conditions.

2. §835.502 High and Very High Radiation Areas
  - (a) The following measures shall be implemented for each entry into a high radiation area:
    - (1) The area shall be monitored as necessary during access to determine the exposure rates to which the individuals are exposed; and
    - (2) Each individual shall be monitored by a supplemental dosimetry device or other means capable of providing an immediate estimate of the individual's equivalent dose to the whole body during the entry.
  - (b) Physical controls. One or more of the following controls shall be used for each entrance or access point to a high radiation area where radiation levels exist such that an individual could exceed an equivalent dose to the whole body of 1 rem (0.01 sievert) in any one hour at 30 centimeters from the source or from any surface that the radiation penetrates:
    - (1) A control device that prevents entry to the area when high radiation levels exist or that, upon entry, causes the radiation level to be reduced below the level that defines a high radiation area;
    - (2) A device that functions automatically to prevent use or operation of the radiation source or field while individuals are in the area;
    - (3) A control device that energizes a conspicuous visible or audible alarm signal so that the individual entering the high radiation area and the supervisor of the activity are made aware of the entry;
    - (4) Entryways that are locked. During periods when access to the area is required, positive control over each entry is maintained;
    - (5) Continuous direct or electronic surveillance that is capable of preventing unauthorized entry;
    - (6) A control device that will automatically generate audible and visual alarm signals to alert personnel in the area before use or operation of the radiation source and in sufficient time to permit evacuation of the area or activation of a secondary control device that will prevent use or operation of the source.

- (c) Very high radiation areas. In addition to the above requirements, additional measures shall be implemented to ensure individuals are not able to gain unauthorized or inadvertent access to very high radiation areas.
- (d) No control(s) shall be established in a high or very high radiation area that would prevent rapid evacuation of personnel.
3. Besides meeting the requirements for entry into Radiological Areas and RBAs, personnel must also ensure that they take appropriate measures to maintain their exposures ALARA. Objective 2.10.12
- a. Workers who receive radiation exposures from other nuclear facilities must report the exposure to radiological control and their supervisor upon returning to the site.
  - b. Avoid contact with potentially contaminated surfaces.
  - c. Any management/supervision or RCT personnel should give stop work or evacuation orders if unanticipated radiation or contamination is encountered or if the appropriate RWP is not being followed.
  - d. Wear dosimeter(s) in accordance with the RWP.
  - e. Maintain exposure ALARA.
  - f. Report all injuries.
  - g. Monitor clothing and exposed skin as required and report the presence of radioactive contamination. See DOE RCS Art. 338 and Appendix 3D (or appropriate site document)
  - h. Place contaminated items and waste in approved radioactive waste containers.
  - i. Personnel should wash their hands when leaving the RBA and prior to eating or using tobacco products.
  - j. Personnel who are not respirator qualified shall not enter areas posted as "Respiratory Protection Required".
4. Hot Particles
- a. Hot particles are small, discrete, highly radioactive particles capable of causing extremely high doses to a localized area in a short period of time. Hot particle contamination may be present or be generated when contaminated systems are opened or when operations such as machining, cutting, or grinding are performed on highly radioactive materials.

- b. The site-specific Radiological Controls Manuals usually define hot particles. Typically they will be described as very small discrete particles capable of producing an equivalent dose to the skin greater than 100 mrem in one hour.
- c. Special surveys in areas with the potential for hot particle contamination.
- d. Posting areas to specifically identify the presence of hot particles.
- e. Controlling access to hot particle areas should be through a job-specific RWP. The following controls should be considered for inclusion on the RWP:
  - 1) Periodic personnel monitoring during the work activity, at a frequency based on the potential magnitude of skin exposure
  - 2) Additional personal protective equipment and clothing
  - 3) Direct radiological control coverage during work or assistance during protective clothing removal
  - 4) Use of sticky pads or multiple step-off pads
- f. Personal protective equipment and clothing used in hot particle areas should be segregated from other radiological protective equipment and clothing during laundering and surveyed prior to reuse
- g. Response to hot particle skin contamination of personnel should include the following:
  - 1) Immediate removal and retention of the hot particle for subsequent analysis
  - 2) Analysis of the particle
  - 3) Assessment of worker dose
  - 4) Evaluation of work control adequacy

#### G. REMOVING MATERIALS FROM RADIOLOGICAL AREAS

Objective 2.10.13

Facility operations require that radioactive material and non-radioactive material be removed from Radiological Areas, RBAs, and from the site. Prior to allowing this material to leave, important steps outlined in the procedures must be followed. 10 CFR 835 requires the following:

1. §835.1101 Control of material and equipment

- (a) Except as provided below, material and equipment in contamination areas, high contamination areas, and airborne radioactivity areas shall not be released to a controlled area if:
    - (1) Removable contamination levels on accessible surfaces exceed the removable surface contamination values specified in Appendix D of 10 CFR 835; or
    - (2) Prior use suggests that the removable contamination levels on inaccessible surfaces are likely to exceed the removable surface contamination values specified in Appendix D of 10 CFR 835.
  - (b) Material and equipment exceeding the removable surface contamination levels specified in Appendix D of 10 CFR 835 may be conditionally released for movement on-site from one radiological area for immediate placement in another radiological area only if appropriate monitoring is performed and appropriate controls for the movement are established and exercised.
  - (c) Material and equipment with fixed contamination levels that exceed the limits specified in Appendix D of 10 CFR 835 may be released for use in controlled areas outside of the radiological areas only under the following conditions:
    - (1) Removable surface contamination levels are below the removable surface contamination values specified in Appendix D of 10 CFR 835; and
    - (2) The material or equipment is routinely monitored and clearly marked or labeled to alert personnel of the contaminated status.
2. Release to Radiological Buffer Areas
- (Insert site specific information here)*
3. Release to Uncontrolled Areas
- (Insert site specific information here)*



### III. SUMMARY

#### A. Review major topics

1. RWPs
2. Radiological postings
3. Setting up radiological areas
4. Good practices and discrepancies commonly observed in setup of various portions of radiological areas.
5. Access control
6. Removing materials from radiological areas

#### B. Review learning objectives

### IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.

**Course Title:** Radiological Control Technician  
**Module Title:** Radiological Work Coverage  
**Module Number:** 2.11

**Objectives:**

- 2.11.01 List four purposes of job coverage.
- 2.11.02 Explain the differences between continuous and intermittent job coverage.
- 2.11.03 Given example conditions, identify those that should require job coverage.
- 2.11.04 Identify items that should be considered in planning job coverage.
- 2.11.05 Identify examples of information that should be discussed with workers during pre-job briefings.
- 2.11.06 Describe exposure control techniques that can be used to control worker and technician radiation exposures.
- 2.11.07 Describe the in-progress radiological surveys that should be performed, at your site, under various radiological conditions.
- 2.11.08 Describe site requirements for documentation of in-progress radiological surveys.
- 2.11.09 Explain actions that should be taken if surveys show radiological conditions significantly different from that expected.
- 2.11.10 Describe contamination control techniques that can be used to limit or prevent personnel and area contamination and/or reduce radioactive waste generation.
- 2.11.11 Describe job coverage techniques that can be used to prevent or limit the spread of airborne radioactive material.
- 2.11.12 Describe overall job control techniques in maintaining control of radiological work.
- 2.11.13 State the reasons to stop radiological work activities in accordance with the DOE RCS.

**References:**

1. DOE Radiological Control Standard (2008).

**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

The purpose of job coverage by RCTs is to assist workers in keeping their radiation exposures ALARA.

## C. Overview of Lesson

1. Explanation of job coverage
2. Conditions requiring job coverage
3. Prerequisites for planning job coverage
4. Job coverage techniques

## D. Introduce Objectives

O.H.: Objectives

**II. LESSON OUTLINE**

## A. Explanation of Term "Job or Work Coverage"

1. Purposes
  - a. Radiation exposure control
    - 1) Keep ALARA
    - 2) Keep within limits

Ask students what is meant by job or work coverage. Modify their answers for correctness.

Objective 2.11.01  
Ask students for the purposes of job coverage. Modify their answers for coverage and list on blackboard.

- b. Contamination control
    - 1) Reduce creation
    - 2) Reduce spread
  - c. Airborne radioactive material control
    - 1) Reduce creation
    - 2) Reduce spread
  - d. Radioactive waste
    - Reduce creation
2. Types Objective 2.11.02
- a. Continuous
    - Technician remains at the job site during entire job and covers only that job
  - b. Intermittent
    - Coverage of more than one job or periodic checks for job coverage
- B. Conditions Requiring Job Coverage Objective 2.11.03
- 1. Workers doses near limits
  - 2. Radiation levels increase significantly
  - 3. Entry to some high radiation levels
  - 4. Spreading contamination or airborne
  - 5. Contamination or airborne levels increase significantly
  - 6. Questions regarding the adequacy of personnel dosimetry being used
  - 7. Inexperienced workers
- Ask the students for conditions that could require job coverage. Modify their answers and write on the board. After you write on the board, give an example of each condition.

## C. Prerequisites for Planning Job Coverage

1. Detailed job description
2. Review past problem areas
  - a. Review surveys
  - b. Talk with technicians
  - c. Review applicable Post Job ALARA Reviews
3. Review system
  - a. Effects of opening
  - b. Effects of welding, cutting, grinding
4. Detailed survey
  - a. Job site

High and low dose rate areas

    - Extremity dose rates
    - Beta dose rates
    - Hot Spots
    - Other possible hazards
  - b. Pathways to site
  - c. Identify
    - 1) Contamination levels
    - 2) Airborne levels

## Objective 2.11.04

Ask student what items should be planned before going on to the job site. Modify their answers for correctness. Write their answers on the board. Explain why each item must be considered. (See appropriate site document)

Explain that by knowing the dose rate, individuals can avoid areas of highest dose rate and wait in low dose rate areas.

5. Record workers' allowable exposures
  6. Communications with workers
    - a. Face-to-face
    - b. Hand signals
    - c. Remote headsets
    - d. Safety lines
    - e. Portable radios
  7. Communications with lab
    - a. Transferring air samples
    - b. Results of surveys, samples
  8. Equipment at job site
    - a. Dosimeters
    - b. Charger
    - c. Air sampler
    - d. Survey instrument(s)
    - e. Respirator (if needed)
    - f. Watch or clock
    - g. Emergency Actions and Emergency Exits
- Explain that these limits should be written down and taken to the job site. Do not trust memory.
- Ask students how communications can be achieved. Write their answers on the board.
- Ask the students what equipment should be available at the job site. List the equipment on the board. Explain why each could be needed.

### Consideration of Other Hazards

When evaluation the hazards for a job evolution, it is important to consider non-radiological hazards as well. A framework aligned with the principles and functions of Integrated Safety Management (ISM) requires systematically integration of safety into management and work practices at all levels so that missions are accomplished while protecting the public, the worker, and the environment. This is accomplished through effective integration of safety management into all facets of work planning and execution. Under ISM, both DOE and DOE-contractor line managers are charged with responsibility for integrating safety measures into all facets of work planning and execution. Line managers should use their site-specific radiological control manual as a guide to integrating radiological control measures into work planning and execution. Both the ISM and ALARA processes require hazard controls to be tailored to the work being performed. In addition to establishing basic radiological safety standards that must be observed, 10 CFR 835 establishes requirements that provide significant flexibility so that individual activities may implement compliance measures in a manner that is commensurate with specific hazards and work activities.

On December 2, 2002, the 107<sup>th</sup> Congress amended the Atomic Energy Act by adding Section 234.C and on December 18, 2003, DOE published a Notice of Proposed Rulemaking in the Federal Register, entitled, "Worker Safety and Health Program." The Rule became final on February 9, 2006 as 10 CFR 851. This rule provides for a worker health and safety program for DOE contractors and should be addressed in hazard analysis evaluation for radiological operations.



9. Pre-job Briefings
  - a. Radiological conditions
  - b. Effect of job on conditions
  - c. Communications method
  - d. Special dosimetry
  - e. Special protective clothing
  - f. RCT functions
  - g. Importance of following the RWP and its specific directions

Objective 2.11.05  
Explain that by keeping the workers on the job informed, communications will be improved. Ask the students what information should be given to the workers. Write the information on the board.

D. Job Coverage Techniques

1. Exposure Control

Objective 2.11.06  
Explain that the exact techniques used will vary depending on the job, radiological conditions, and worker experience. For each of the following techniques, state the technique and why it is necessary. Teach as a discussion.

Write "Exposure Control" on the board. List the techniques under this heading. Leave these techniques under this heading. Leave these techniques on the board. Use the same method for Sections 2-4, so that at the end of the lecture all four headings and the respective techniques will be on the board.

- a. Perform frequent surveys during job performance
    - 1) Purpose and types of surveys
    - 2) Base on probability of conditions changing
    - 3) Required by operational procedures
    - 4) Document Surveys
      - a) Purpose
      - b) Requirement
    - 5) Report unusual conditions to management
    - 6) Verify dose rates remain as posted
  
  - b. Wait in low dose rate areas
    - 1) Purpose
    - 2) Identify from survey
    - 3) Reduces time in radiation area
  
  - c. Check dosimeters
    - 1) Purpose
      - Accumulated dose
    - 2) Technician reads
    - 3) Have workers read
    - 4) Reduce contamination of dosimeter
      - a) Remove outer glove
      - b) Use clean glove
- For examples of when surveys are required during job performances, refer to site procedures.
- Ask students how this can reduce dose received. Modify answers for correctness.

- d. Determine time allowed in areas
- Time = Authorized Exposure/Dose Rate
- e. Workers location vs. dose rate
- 1) Purpose
- Determine dose received
- 2) Dose = Dose Rate x Time
- f. Document workers' locations and times
- Purpose
- Prevent reliance on memory
  - Inaccurate dose estimates
- g. Workers dosimetry location vs. dose rate
- 1) Purpose
- Dose estimation
- 2) May require special dosimetry
    - a) Finger badges
    - b) Extremity
    - c) Head
- h. Modify temporary shielding
- 1) Purpose
- Prevent un-evaluated exposure rates
- 2) Must have Rad Con approval
- i. Modify temporary shielding - Rad Con
- Must evaluate before moving

Explain that not all of the time can be allowed for performing the job. Workers may receive significant exposure going to and leaving the job.

Ask the students why this is an important concept. Use a drawing to illustrate an example if necessary.

- |   |  |
|---|--|
| <ul style="list-style-type: none"> <li>j. In-progress radiological surveys<br/><i>(Insert site specific information here)</i></li> </ul>  | Objective 2.11.07  |
| <ul style="list-style-type: none"> <li>k. In-progress radiological survey documentation<br/><i>(Insert site specific information here)</i></li> </ul>   | Objective 2.11.08  |
| <ul style="list-style-type: none"> <li>l. Unexpected radiological conditions<br/><i>(Insert site specific information here)</i></li> </ul>  | Objective 2.11.09  |
| <ul style="list-style-type: none"> <li>1. Contamination Control</li> </ul>  | Objective 2.11.10<br>Write "Contamination Control" beside "Exposure Control." List each technique beneath Contamination Control. |
| <ul style="list-style-type: none"> <li>a. Watch workers           <ul style="list-style-type: none"> <li>1) Purpose<br/>Lessen personnel and area contamination</li> <li>2) Look for               <ul style="list-style-type: none"> <li>a) Hand to face movements</li> <li>b) Dropping tools</li> <li>c) Hammering</li> <li>d) Scuffing feet</li> <li>e) Wire brushing</li> </ul> </li> </ul> </li> </ul> | Ask the Students what actions they should be looking for.  |
| <ul style="list-style-type: none"> <li>b. Transferring material           <ul style="list-style-type: none"> <li>1) Bagging</li> <li>2) Plastic sheets</li> <li>3) Floor cover for pathway</li> </ul> </li> </ul>   | Thoroughly cover all of the correct practices in bagging tools, trash or equipment.  |

- c. Tools and equipment
- Methods
- Taping
  - Using previously contaminated tools
- d. Equipment going from contaminated to clean areas
- Examples
- Crane rigging
  - Air and water hoses (secure hoses/lines)
- e. Reduce radioactive waste
- 1) Purpose
    - a) Reduce contamination
    - b) Reduce costs
    - c) Reduce processing time
    - d) Reduce dose
  - 2) Techniques
    - a) Remove packing material
    - b) Minimize water for decon
3. Airborne Radioactivity Control
- Ask students what steps can be taken to lessen the probability of contaminating tools and equipment before use.
- Ask the student for examples of equipment that may go from contaminated to clean areas.
- Write "Airborne Radioactivity Control" on the board. List the techniques beneath this heading.

- a. Actions creating airborne
  - 1) Actions causing
    - a) Opening systems
    - b) Welding, grinding, cutting
    - c) Hammering
    - d) Wire brushing
    - e) Sweeping
    - f) Leaks and sprays
    - g) Air hose systems/tools
  - 2) Corrective actions
- b. Portable air samples
  - 1) Purpose
    - Identify problem
  - 2) Analyze in lab
    - Time delay
  - 3) Corrective measures
- c. Continuous air monitors (CAMs)
  - 1) Purpose
    - Identify problem
  - 2) Immediate indication

Objective 2.11.11  
Ask the students what actions could create airborne. Modify their answers for correctness.

Ask students for a disadvantage of analyzing the sample in a lab.

Ask the students for an advantage of CAMs vs. portable air samples.

- 3) Corrective measures
- d. Ventilate enclosed areas
  - 1) Purpose
    - a) Remove airborne
    - b) Contain airborne
  - 2) Installed ventilation
  - 3) Temporary Ask students for examples of temporary ventilation.
    - a) Fans with hose and HEPA filters
    - b) Hose from installed duct of HVAC
    - c) Tents
- 4. Overall Job Control Techniques
  - a. Establish worker trust and confidence
    - 1) Purpose
      - Improve communications
    - 2) Earned not given
    - 3) Techniques
      - a) Reliable
      - b) Realistic
      - c) Credible
      - d) Consistent

Ask the students for the disadvantages of CAMs compared to portable samplers.

Objective 2.11.12  
Write "Overall Job Control" on the board. List the techniques beneath this heading.

Ask students for characteristics of people they trust. Point out that they should develop the same characteristics to earn worker trust.

- b. Keep workers in sight
    - 1) Purpose
      - a) Identify poor work habits
      - b) Correct poor work habits
    - 2) Sometimes impossible
  - c. Keep contact with workers
    - 1) Purpose
      - a) Improve rapport
      - b) Alleviate worker apprehension
    - 2) Techniques
      - a) Face to face
      - b) Remote communications
  - d. Workers' Notification to RC
    - 1) Purpose
      - Prevent un-evaluated radiological conditions
    - 2) Before opening systems
    - 3) Before changing work techniques
  - e. Correct poor work habits
    - 1) Purpose
      - a) Prevent contamination of workers and area
      - b) Keep doses ALARA
- Explain that most workers are apprehensive when using remote communications. Staying in contact alleviates their concerns.
- State that even though RWP's usually require workers to notify RC, the technician should remind the workers of the requirement and explain the reasons why to the workers.



- 2) Techniques
  - a) Offer as advice
  - b) Explain consequences
  - c) Explain proper method
- f. Show a positive, helpful attitude toward co-workers

Purpose

- Improve communications
  - Improve credibility
- g. Don't overreact
    - 1) Consequence
    - 2) Remain calm
  - h. Stop Work Authority
    - 1) Purpose
    - 2) Maintain Control
    - 3) Reevaluate situation
    - 4) Correct problem before allowing work to continue
    - 5) Stop work when:
      - a) Inadequate radiological controls
      - b) Radiological controls not being implemented
      - c) Radiological hold point not being satisfied

Objective 2.11.13

Teach as a discussion. Present the students with the problem area and ask for the consequences of the problem and how the problem could be solved. Note that more than one answer could be correct. Encourage student participation by asking if there are more ideas or if they are all in agreement with the solution.

- d) Any workers dosimeter alarms or exhibits unexpected readings
- 6) Example situation of when to use stop work authority
- 5. Common problem areas
  - a. Remaining in work area, not lower exposure area.
  - b. Leaning or sitting on high contact dose rate equipment.
  - c. Not using existing shielding to full advantage.
  - d. Improperly handing item out of controlled area.
  - e. Not catching radioactive liquids (if applicable).
  - f. Creating unnecessary radwaste.
  - g. Improperly ventilating areas.
  - h. Removing high dose rate items from work areas.
  - i. Moving crane rigging in and out of contaminated areas.
  - j. Improperly controlling hot sparks and burning slag when welding.
  - k. Remaining in high dose rate areas beyond time allowed.
  - l. Opening systems or containers before notifying RC.
  - m. Changing work methods before notifying RC.

**III. SUMMARY**

- A. Review major points
  - 1. Explanation of job coverage
  - 2. Conditions requiring job coverage
  - 3. Prerequisites for planning job coverage
  - 4. Job coverage techniques
- B. Review learning objectives

**IV. EVALUATION**

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.

**Course Title:** Radiological Control Technician  
**Module Title:** Shipment/Receipt of Radioactive Material  
**Module Number:** 2.12

**Objectives:**

- 2.12.01 List the applicable agencies which have regulations that govern the transport of radioactive material.
- 2.12.02 Define terms used in DOT regulations.
- 2.12.03 Describe methods that may be used to determine the radionuclide contents of a package.
- 2.12.04 Describe the necessary radiation and contamination surveys to be performed on packages and state the applicable limits.
- 2.12.05 Describe the necessary radiation and contamination surveys to be performed on exclusive use vehicles and state the applicable limits.
- 2.12.06 Identify the proper placement of placards on a transport vehicle.
- 2.12.07 Identify inspection criteria that should be checked prior to releasing a shipment at your site.
- 2.12.08 Describe site procedures for receipt and shipment of radioactive material shipments.
- 2.12.09 List the actions required at your site if a shipment is received exceeding radiation or contamination limits.
- 2.12.10 Describe the proper step-by-step method for opening a package containing radioactive material at your site.

**REFERENCES**

1. 10 CFR 835 (2007), "Occupational Radiation Protection".
2. 49 CFR, Parts 100-177, "Transportation".
3. DOE Order 460.1B (2003), "Packaging and Transportation Safety".
4. DOE Order 460.2 A (2004), "Departmental Materials Transportation and Packaging Management".

**I. MODULE INTRODUCTION**

## A. Self Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

The basis behind the regulations governing the packaging and shipping of radioactive material is to keep radiation and radioactive material from affecting the environment during transportation and to keep the environment from affecting the integrity of the radioactive material.

The package itself is to be designed and constructed to be the effective barrier between the environment and the radioactive material, thus most of the regulatory restrictions apply to the package and the method of shipment used to transport the package.

To reduce any potential hazard, the regulatory requirements become more restrictive as the quantity, concentration, and potential hazard of the radioactive material increases.

## C. Overview of Lesson

This unit will present an overview of shipping and transportation regulations and methods for radioactive materials.

## D. Introduce Objectives

O.H.: Objectives

**II. MODULE OUTLINE**

## A. Regulatory Structure

Objective 2.12.01

Numerous governmental agencies have jurisdiction over the transfer and shipment of radioactive material from nuclear facilities. The primary organizations are:

- U.S. Department of Energy
- U.S. Nuclear Regulatory Commission
- U.S. Department of Transportation, Hazardous Material Bureau
- U.S. Coast Guard
- International Civil Aviation Organization or International Air Transport Association
- State transportation departments or radiation health bureaus.

**B. U.S. Department of Energy**

The U.S. DOE establishes regulations to protect the public health and safety from undue risk from DOE activities. These regulations are in the form of 10 CFR 835 and DOE Orders. DOE requirements applicable to packaging and transportation of radioactive material include:

**1. 10 CFR 835**

The Exclusion section of 10 CFR 835.1 states that occupational doses received as a result of excluded activities and radioactive material transportation shall be considered when determining compliance with the occupational dose limits in §§835.202 and 835.207.

**2. DOE O 460.1B**

- a. Establishes administrative procedures for the certification and use of radioactive and other hazardous materials packaging by DOE.
- b. Establishes standards and requirements for the packaging and transportation of hazardous (including radioactive) materials, substances and wastes. This Order requires that packages for radioactive materials meet the NRC standards in 10 CFR 71 and imposes additional restrictions.

**3. DOE Order 460.2**

Establishes DOE policies and procedures for the management of materials transportation activities, including traffic management, for other than intrabuilding and intrasite transfers. It contains general requirements related to all transportation activities, not just hazardous or radioactive materials.

#### 4. U.S. Department of Transportation

The U.S. DOT regulates transportation by air, water, rail, and highway. The Materials Transportation Bureau has established rules governing the packaging and transport of hazardous material, including radioactive material.

These regulations are contained in 49 CFR 170 - 179 and are applicable to any person who transports, or ships, a hazardous material. Even though most of the requirements for shipping radioactive material are located in Part 173, the other sections of DOT regulations must not be overlooked.

#### C. Regulatory Compliance

There are many regulations and documents from several agencies that govern the transfer and transport of radioactive material. Compliance with all regulations, not just those from one agency, is required to transfer and shipment of radioactive material. The number of regulations involved depends upon the chosen mode of transport and the quantity of radioactive material. Each individual or group assigned the responsibility of transferring and shipping radioactive material must maintain a complete set of current regulations from all applicable agencies as well as other supporting regulatory guides, licenses and clarifying documents.

Keep in mind that most regulations usually contain exemptions and may contain more restrictive clauses. For example, the DOT may exempt some shipments of low quantities and types of radioactive material from their regulations. The DOT exemption, however, does not automatically exempt the material from DOE requirements. It is best to be aware of the requirements from all agencies to avoid citations for using one specific exemption that is not recognized by the other agencies.

#### D. Definition of Terms

Objective 2.12.02

The following definitions are found in 49 CFR 173.403 (this is not a complete listing of the §173.403 definitions):

1. A<sub>1</sub>. The maximum activity of special form radioactive material permitted in a Type A package.

2. A<sub>2</sub>. The maximum activity of radioactive material, other than special form, Low Specific Activity, or Surface Contaminated Object, permitted in a Type A package.
3. Radioactive Material. Any material having a specific activity greater than 70 Bq per gram (0.002 microcurie per gram). No other U.S. Department or Agency uses this limit.
4. Exclusive Use (also referred to as “sole use” or “full load”). Sole use by a single consignor of a conveyance for which all initial, intermediate, and final loading and unloading are carried out in accordance with the direction of the consignor or the consignee. The consignor and the carrier must ensure that any loading or unloading is performed by personnel having radiological training and resources appropriate for safe handling of the consignment. The consignor must issue specific instructions in writing, for maintenance of exclusive use shipment controls, and include them with the shipping paper information provided to the carrier by the consignor.
5. Limited Quantity. A quantity of radioactive material not exceeding the materials packaging limits specified in §173.425 and conforming with requirements specified in §173.421.
6. Low Specific Activity (LSA). Radioactive material with limited specific activity which satisfies the descriptions and limits set forth below. Shielding materials surrounding LSA material may not be considered in determining the estimated average specific activity of the package contents. LSA material must be in one of three groups:
  - 1) LSA-I
    - i) Ores containing only naturally occurring radionuclides (e.g., uranium, thorium) and uranium or thorium concentrates of ores; or
    - ii) Solid unirradiated natural uranium or depleted uranium or natural thorium or their solid or liquid compounds or mixtures; or
    - iii) Radioactive material, other than fissile material, for which the A<sub>2</sub> value is unlimited; or
    - iv) Mill tailings, contaminated earth, concrete, rubble, other debris, and activated material in which the radioactive material is essentially uniformly distributed and the average specific activity does not exceed 10<sup>-6</sup>A<sub>2</sub>/g.

- 2) LSA-II



- i) Water with tritium concentration up to 0.8 Tbq/liter (20 Ci/liter); or
    - ii) Material in which the radioactive material is distributed throughout and the average specific activity does not exceed  $10^{-4} A_2/g$  for solids and gases, and  $10^{-5} A_2/g$  for liquids.
  - 3) LSA-III: Solids (e.g., consolidated wastes, activated materials) that meet the requirements of §173.468 and which:
    - i) The radioactive material is distributed throughout a solid or a collection of solid objects, or is essentially uniformly distributed in a solid compact binding agent (such as concrete, bitumin, ceramic, etc.); and
    - ii) The radioactive material is relatively insoluble, or it is intrinsically contained in an insoluble material, so that even under loss of packaging, the loss of radioactive material per package by leaching when placed in water for seven days would not exceed  $0.1 A_2$ ; and
    - iii) The average specific activity of the solid does not exceed  $2 \times 10^{-3} A_2/g$ .
7. Normal Form. Radioactive material which has not been demonstrated to qualify as Special Form radioactive material. In other words, this includes most radioactive material shipped, except encapsulated sources with the "Special Form" certification.
8. Package. The packaging together with its radioactive contents as presented for transport.
  - 1) Excepted Package means a packaging together with its excepted radioactive materials as specified in §§173.421-173.426 and 173.428.
  - 2) Type A Package means a packaging that, together with its radioactive contents limited to  $A_1$  or  $A_2$  as appropriate, meets the requirements of §§173.410 and 173.412 and is designed to retain the integrity of containment and shielding required by Part 173 under normal conditions of transport as demonstrated by the tests set forth in §173.465 or §173.466, as appropriate.
  - 3) Type B Package means a packaging that, together with its radioactive contents, is designed to retain the integrity of containment and shielding required by Part 173 when subjected to the normal conditions of transport and hypothetical accident test conditions set forth in 10 CFR 71. There are specific

Type B packages, which include Type B(U) and Type B(M) packages. Their requirements are specified in §173.403.

- 4) Industrial Packaging means a packaging that, together with its Low Specific Activity material or Surface Contaminated Object contents, meets the requirements of §§173.410 and 173.411. Industrial Packaging is further categorized in §173.411 as Type 1, Type 2, or Type 3.
9. Packaging. The assembly of components necessary to ensure compliance with the packaging requirements of Part 173, Subpart I. It may consist of one or more receptacles, absorbent materials, spacing structures, thermal insulation, radiation shielding, service equipment for filling, emptying, venting and pressure relief, and devices for cooling or absorbing mechanical shocks. The conveyance, tie-down system, and auxiliary equipment may sometimes be designated as part of the packaging.
10. Special Form. Radioactive material which satisfies the following conditions:
  - 1) It is either a single solid piece or is contained in a sealed capsule that can be opened only by destroying the capsule;
  - 2) The piece or capsule has at least one dimension not less than 5 millimeters (0.2 inch); and
  - 3) It satisfies the test requirements of §173.469. There are other specific special form encapsulation design exceptions found elsewhere in Part 173.
11. Surface Contaminated Object (SCO). A solid object which is not itself radioactive but which has radioactive material distributed on any of its surfaces. SCO must be in one of two groups with surface activity not exceeding the following limits:
  - 1) SCO-I: A solid object on which:
    - i) The non-fixed contamination on the accessible surface averaged over 300 cm<sup>2</sup> (or the area of the surface if less than 300 cm<sup>2</sup>) does not exceed 4 Bq/cm<sup>2</sup> (10<sup>-4</sup> microcurie/cm<sup>2</sup>) for beta and gamma and low toxicity alpha emitters, or 0.4 Bq/cm<sup>2</sup> (10<sup>-5</sup> microcurie/cm<sup>2</sup>) for all other alpha emitters;
    - ii) The fixed contamination on the accessible surface averaged over 300 cm<sup>2</sup> (or the area of the surface if less than 300 cm<sup>2</sup>) does not exceed 4x10<sup>4</sup> Bq/cm<sup>2</sup> (1.0 microcurie/cm<sup>2</sup>) for beta and gamma and low toxicity alpha emitters, or 4x10<sup>3</sup> Bq/cm<sup>2</sup> (0.1 microcurie/cm<sup>2</sup>) for all other alpha emitters.

- iii) The non-fixed contamination plus the fixed contamination on the accessible surface averaged over  $300 \text{ cm}^2$  (or the area of the surface if less than  $300 \text{ cm}^2$ ) does not exceed  $4 \times 10^4 \text{ Bq/cm}^2$  ( $1.0 \text{ microcurie/cm}^2$ ) for beta and gamma and low toxicity alpha emitters, or  $4 \times 10^3 \text{ Bq/cm}^2$  ( $0.1 \text{ microcurie/cm}^2$ ) for all other alpha emitters.
- 2) SCO-II: A solid object on which the limits for SCO-I are exceeded and on which:
- i) The non-fixed contamination on the accessible surface averaged over  $300 \text{ cm}^2$  (or the area of the surface if less than  $300 \text{ cm}^2$ ) does not exceed  $400 \text{ Bq/cm}^2$  ( $10^{-2} \text{ microcurie/cm}^2$ ) for beta and gamma and low toxicity alpha emitters, or  $40 \text{ Bq/cm}^2$  ( $10^{-3} \text{ microcurie/cm}^2$ ) for all other alpha emitters;
  - ii) The fixed contamination on the accessible surface averaged over  $300 \text{ cm}^2$  (or the area of the surface if less than  $300 \text{ cm}^2$ ) does not exceed  $8 \times 10^5 \text{ Bq/cm}^2$  ( $20 \text{ microcurie/cm}^2$ ) for beta and gamma and low toxicity alpha emitters, or  $8 \times 10^4 \text{ Bq/cm}^2$  ( $2 \text{ microcurie/cm}^2$ ) for all other alpha emitters; and
  - iii) The non-fixed contamination plus the fixed contamination on the accessible surface averaged over  $300 \text{ cm}^2$  (or the area of the surface if less than  $300 \text{ cm}^2$ ) does not exceed  $8 \times 10^5 \text{ Bq/cm}^2$  ( $20 \text{ microcurie/cm}^2$ ) for beta and gamma and low toxicity alpha emitters, or  $8 \times 10^4 \text{ Bq/cm}^2$  ( $2 \text{ microcurie/cm}^2$ ) for all other alpha emitters.
12. Transport Index. The dimensionless number (rounded up to the next tenth) placed on the label of a package to designate the degree of control to be exercised by the carrier during transportation.
13. Type A Quantity. A quantity of radioactive material, the aggregate radioactivity of which does not exceed  $A_1$  for special form radioactive material or  $A_2$  for normal form radioactive material.
14. Type B Quantity. A quantity of radioactive material greater than a Type A quantity.

#### E. Application of Regulatory Requirements

##### 1. Radioactive Contents

Objective 2.12.03

In order to determine packaging, labeling and other requirements for shipping radioactive material, the radionuclide content of the material must be known. This includes the identity and quantity of each isotope.

There are four basic methods which are considered acceptable for radionuclide identification.

- a. materials accountability - primarily applicable to wastes and involves determining the quantity of radioactive material contained within a volume by comparing the amount of radioactive material entering and exiting a given process.
- b. classification by source - determining the radionuclide content through knowledge and control of the source of the material.
- c. gross radioactivity measurements - acceptable, provided that:
  - i. the gross radioactivity measurements are correlated to the actual radionuclides in the material
  - ii. the gross measurement is initially correlated to actual radionuclide content and periodically verified
- d. direct measurement of individual radionuclides - individual gamma emitting radionuclides are directly measured using gamma spectroscopy.

#### F. Package Radiation Surveys and Limits

Objective 2.12.04

Except as provided in paragraph (b) of §173.441, each package of radioactive materials offered for transportation must be designed and prepared for shipment, so that under conditions normally incident to transportation, the radiation level does not exceed 2 mSv/hour (200 mrem/hour) at any point on the external surface of the package, and the transport index does not exceed 10.

A package which exceeds 2 mSv/hour (200 mrem/hour) or a transport index of 10 must be transported by exclusive use shipment, and the radiation levels for such shipment may not exceed the following during transportation:

1. 2 mSv/h (200 mrem/h) on the external surface of the package unless the following conditions are met, in which case the limit is 10 mSv/h (1000 mrem/h):
  - a. The shipment is made in a closed transport vehicle;

- b. The package is secured within the vehicle so that its position remains fixed during transportation; and
  - c. There are no loading or unloading operations between the beginning and end of the transportation;
2. 2 mSv/h (200 mrem/h) at any point on the outer surfaces of the vehicle, including the top and underside of the vehicle; or in the case of a flat-bed style vehicle, at any point on the vertical planes projected from the outer edges of the vehicle, on the upper surface of the load or enclosure if used, and on the lower external surface of the vehicle;
  3. 0.1 mSv/h (10 mrem/h) at any point 2 meters (6.6 feet) from the outer lateral surfaces of the vehicle (excluding the top and underside of the vehicle); or in the case of a flat-bed style vehicle, at any point 2 meters (6.6 feet) from the vertical planes projected by the outer edges of the vehicle (excluding the top and underside of the vehicle); and
  4. 0.02 mSv/h (2mrem/h) in any normally occupied space, except that this provision does not apply to carriers if they operate under the provisions of a State or federally regulated radiation protection program and if personnel under their control who are in such an occupied space wear radiation dosimetry devices.

For shipments made under the exclusive use provisions, the offeror shall provide specific written instructions for maintenance of the exclusive use shipment controls to the carrier. The instructions must be included with the shipping paper information. The instructions must be sufficient so that, when followed, they will cause the carrier to avoid actions that will unnecessarily delay delivery or unnecessarily result in increased radiation levels or radiation exposures to transport workers or members of the general public.

Packages exceeding 2 mSv/hour (200 mrem/hour) or a transport index of 10 may not be transported by aircraft.

- G. Contamination Surveys and Limits (Off-site shipments via non-DOE conveyance)

The level of non-fixed (removable) radioactive contamination on the external surfaces of each package offered for transport must be kept as low as reasonably achievable. The level of non-fixed radioactive contamination may not exceed the limits set forth in Table 11 of §173.443 and must be determined by either:

1. Wiping an area of 300 square centimeters of the surface concerned with an absorbent material, using moderate pressure, and measuring the activity on the wiping material. Sufficient measurements must be taken in the most appropriate locations to yield a representative assessment of the non-fixed contamination levels. The amount of radioactivity measured on any single wiping material, when averaged over the surface wiped, may not exceed the limits set forth in Table 11 of §173.443 at any time during transport; or
2. Using other methods of assessment of equal or greater efficiency, in which case the efficiency of the method used must be taken into account and the non-fixed contamination on the external surfaces of the package may not exceed ten times the limits set forth in Table 11 of §173.443, as follows:

Table 1 - DOT Contamination Limits (Table 11 of §173.443)

Objective 2.12.05

Contaminant	Maximum Permissible Limits		
	Bq/cm <sup>2</sup>	µCi/cm <sup>2</sup>	dpm/cm <sup>2</sup>
Beta and gamma emitters and low toxicity alpha emitters	0.4	10 <sup>-5</sup>	22
All other alpha emitting radionuclides	0.04	10 <sup>-6</sup>	2.2

§173.428 states that a packaging which previously contained radioactive materials and has been emptied of contents as far as practical, is excepted from the shipping paper and certification, marking and labeling requirements of this Part 173, provided that

- a. The packaging meets the requirements of Sec. 173.421(a) (2), (3), and (5) of this §173 Subpart I;
  - b. The packaging is in unimpaired condition and is securely closed so that there will be no leakage of radioactive material under conditions normally incident to transportation;
  - c. Internal contamination does not exceed 100 times the limits in §173.443(a);
  - d. Any labels previously applied in conformance with Subpart E of §172 are removed, obliterated, or covered and the "Empty" label prescribed in §172.450 is affixed to the packaging; and
  - e. The packaging is prepared for shipment as specified in §173.422.
- H. Contamination Surveys and Limits (On-site and off-site shipments by DOE conveyance)

49 CFR 172 through 173 describe requirements for inspecting and surveying packages, containers and transport conveyances prior to off-site transport. The 49 CFR 173 contamination values shall be used as controlling limits for off-site shipments transported by DOE and non-DOE conveyances. These limits also apply to on-site transfers of shipments by non-DOE conveyances received from or destined to off-site locations.

On-site shipments by DOE conveyances may use alternative DOE limits for contamination, radiation, packaging, etc., provided the alternative is approved.

DOE Radiological Control Standard, Table 2-2, contamination values may be used as controlling limits for on-site and off-site transportation when using a DOE conveyance. When a shipment is received from an off-site destination, in or on a non-DOE conveyance, the 49 CFR contamination values shall be used when transfers are made in a DOE conveyance from the on-site receiving location to the ultimate on-site destination.

#### I. Package Marking, Sealing and Labeling.

§173.427 states that for LSA material and SCO required to be consigned as exclusive use for domestic transportation only, packages are excepted from the marking and labeling requirements of this subchapter. However, the exterior of each nonbulk package must be stenciled or otherwise marked "Radioactive--LSA" or "Radioactive--SCO", as appropriate, and nonbulk packages that contain a hazardous substance must also be stenciled or otherwise marked with the letters "RQ" in association with the above description.

Except as provided above, LSA material and SCO must be packaged as follows:

1. In an industrial package;
2. For domestic transportation only, in a Type A package. The requirements of §173.412 (a), (b), (c) and (k) do not apply;
3. For domestic transportation only, in a strong, tight package that prevents leakage of the radioactive content under normal conditions of transport. In addition to the requirements of paragraph (a) of §173.427, the following requirements must be met:
  - a. The shipment must be exclusive use;
  - b. The quantity of radioactive material in each packaging may not exceed an  $A_2$  quantity;

4. For domestic transportation only, in a packaging that complies with the provisions of 10 CFR 71.52, and is transported in exclusive use; or
5. Any Type B, B(U) or B(M) packaging authorized pursuant to §173.416.

#### J. Type A Packages

In addition to meeting the general design requirements prescribed in §173.410, each Type A packaging must be designed so that

1. The outside of the packaging incorporates a feature, such as a seal, that is not readily breakable, and that, while intact, is evidence that the package has not been opened. In the case of packages shipped in closed transport vehicles in exclusive use, the cargo compartment, instead of the individual packages, may be sealed.
2. The smallest external dimension of the package is not less than 10 centimeters (4 inches).

#### K. Type B Packages

Type B package labeling and marking must meet the following requirements:

1. Follow the same requirements as those described for Type A packages.
2. Follow any additional sealing, labeling, and marking requirements contained in the NRC Certificate of Compliance for the package or site transport plan.

#### L. Surveys of Transport Vehicle

Radiation and contamination surveys should be performed when an Exclusive Use transport vehicle arrives at the site to ensure that the vehicle is not exceeding applicable DOT limits. If found to be above these limits, the vehicle should not be loaded until properly decontaminated and the owner of the transport vehicle and the site packaging and transportation department informed. During loading, exclusive use transport vehicles should be frequently surveyed to avoid the problem of rearranging the load after it is discovered that the radiation levels are above limits.



## M. Vehicle Radiation Surveys

Radiation surveys should be performed at the appropriate locations to ensure that the radiation level limits are not exceeded.

## N. Outgoing Vehicle Contamination Surveys

DOT regulations do not specify contamination limits for transport vehicles other than those designated exclusive use. It is assumed that if packages loaded onto vehicles are kept within their contamination limits, the vehicle will be within the package contamination limits. Contamination surveys of the packages should be conducted at the time of loading to ensure that they have not become contaminated in storage or through handling.

Even though DOT regulations do not specifically require contamination surveys for non-exclusive use vehicles, it is good radiological control practice to perform such surveys to ensure that no contamination is spread to off site areas. Prior to releasing a radioactive material shipment vehicle, survey the bed of the truck, floor, seat, and door handles of the cab, controls in cab, tires, and other areas which could have become contaminated during loading.

Objective 2.12.06

## O. Proper Placarding of Transport Vehicle

1. Do not over-label or placard a vehicle unnecessarily. Application of such placard when the hazard does not exist is a violation of regulations.
2. Description of Placard. The radioactive placard is diamond shaped with "Radioactive" in black centered across it on a white background. The upper portion of the sign has a black radiation symbol on a yellow background (49 CFR 172.556). The placard must be fastened to all four sides of the vehicle (49 CFR 172.504(a)).
3. Location of Placards on Transport Vehicle. Placards must be on all four sides of the vehicle. If a tractor is disconnected from the trailer, placards must be on all four sides of the trailer otherwise the front placard can be on the tractor. After the shipment has been officially received on the receivers property, it is usually posted in accordance with regular posting (Radiation Area, High Radiation Area, Contamination Area, etc.)

## P. Inspection Prior to Release of Shipment

Objective 2.12.07

*(Insert site specific information here)*

## Q. Documentation

For all shipments, the shipping papers must adhere to the requirements of 49 CFR 172.200 through 172.204.

## R. Verification of Receiving Facility's Authorization to Receive the Material

10 CFR 30.41 and 10 CFR 70.42 require that before transferring byproduct and/or special nuclear material, respectively, the shipper must verify that the receiving facility has a license that authorizes the receipt of the material being shipped.

Although these restrictions only apply to NRC licensees, it is good practice to perform the same verification prior to shipping radioactive material to other DOE facilities. Some DOE facilities that normally use only a few isotopes may not have the proper training or instruments to safely receive and control the material. It must also not be assumed that other government agencies are exempt from NRC regulations and license restrictions.

## S. Violations of Regulations

Frequent violations of DOT regulations include:

- Leaking packages
- Contaminated packages and vehicles
- Radiation levels exceeding limits in vehicle cabs, underneath vehicles, and other limits
- Load not securely fastened
- Mechanical deficiencies in the vehicles
- Instructions not provided to carrier for maintaining "exclusive use" of vehicle
- Improper package closure
- Improper packagings for the type or quantity of radioactive material
- Improper or missing markings, labels or placards
- Incomplete and incorrect information on shipping papers.

## T. Receipt of Radioactive Material

Objective 2.12.08

10 CFR 835 requires the following:

1. §835.405 Receipt of radioactive packages.
  - a. If packages containing quantities of radioactive material in excess of a Type A quantity (as defined in 10 CFR 71.4) are expected to be received from radioactive material transportation, arrangements shall be made to either:

- i. Take possession of the package when the carrier offers it for delivery; or
  - ii. Receive notification as soon as practicable after arrival of the package at the carrier's terminal and to take possession of the package expeditiously after receiving such notification.
- b. Upon receipt from radioactive material transportation, external surfaces of packages known to contain radioactive material shall be monitored if the package:
- i. Is labeled with a Radioactive White I, Yellow II, or Yellow III label (as specified in 49 CFR 172.403 and 172.436-440); or
  - ii. Has been transported as low specific activity material on an exclusive use vehicle (as these terms are defined in 10 CFR 71.4); or
  - iii. Has evidence of degradation, such as packages that are crushed, wet, or damaged.
- c. The monitoring required by paragraph (b) shall include:
1. Measurements of removable contamination levels, unless the package contains only special form (as defined at 10 CFR 71.4) or gaseous radioactive material; and
  2. Measurements of the radiation levels, unless the package contains a Type B quantity (as defined in 10 CFR 71.4) of radioactive material.
- d. The monitoring required by paragraph (b) of this section shall be completed as soon as practicable following receipt of the package, but not later than 8 hours after the beginning of the working day following receipt of the package.
- e. Monitoring per § 835.405(b) is not required for packages transported on a DOE site which have remained under the continuous observation and control of an individual who is knowledgeable of and implements required exposure control measures.

*(Insert site specific information here)*

#### U. Shipment of Radioactive Material

*(Insert site specific information here)*

## V. Shipment Exceeding Limits

Objective 2.12.09

If it is known, assumed, or suspected that the delivering vehicle or packages are contaminated, the delivering carrier, all intermediate carriers and the shipper must be notified immediately so that potentially contaminated vehicles can be withdrawn from service and checked. Loading docks and terminals through which the package passed in transit must also be surveyed. If any contamination is found on package surfaces, it is important to check any areas, equipment or personnel who may have become contaminated handling the package. Depending on the extent of contamination, the incident may also require notification to DOE Headquarters under the Unusual Occurrence Reporting system and could result in activation of the Radiological Assistance Plan. If a package was received from an NRC licensee, the director of the NRC Inspection and Enforcement Regional Office should also be notified.

*(Insert site specific information here)*

## V. OPENING PACKAGES OF RADIOACTIVE MATERIAL

Objective 2.12.10

It is good radiological control practice to establish, maintain, and follow procedures for opening packages containing radioactive material.

*(Insert site specific information here)*

**III. SUMMARY**

Radioactive material which is to be transported from one location to another must be properly packaged, surveyed, labeled and documented. Currently there are approximately 50,000 weekly shipments of radioactive material in the U.S. Strict adherence to shipping requirements is requisite to maintain high levels of safety.

**IV. EVALUATION**

Evaluation should consist of a written examination comprised of multiple choice, fill-in-the-blank, matching, and/or short answer questions. 80% should be the minimum passing criteria for examinations.

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**Course Title:** Radiological Control Technician  
**Module Title:** Radiological Incidents and Emergencies  
**Module Number:** 2.13

**Objectives:**

- 2.13.01 Describe the general response and responsibilities of an RCT during any incident.
- 2.13.02 Identify any emergency equipment and facilities that are available, including the location and contents of emergency equipment kits.
- 2.13.03 Describe the RCT response to a Continuous Air Monitor (CAM) alarm.
- 2.13.04 Describe the RCT response to a personnel contamination monitor alarm.
- 2.13.05 Describe the RCT response to off scale or lost dosimetry.
- 2.13.06 Describe the RCT response to rapidly increasing, unanticipated radiation levels or an area radiation monitor alarm.
- 2.13.07 Describe the RCT response to a dry or liquid radioactive material spill.
- 2.13.08 Describe the RCT response to a fire in a radiological area or involving radioactive materials.
- 2.13.09 Describe the RCT response to other specific site incidents (as applicable).
- 2.13.10 Describe the response levels associated with radiological emergencies.
- 2.13.11 Describe site specific procedures for documenting radiological incidents.
- 2.13.12 Identify the structure of the emergency response organization at your site.
- 2.13.13 Identify the available offsite incident support groups and explain the assistance that each group can provide.
- 2.13.14 Discuss radiological incidents at the plant or other plants, including cause, prevention, and recommended incident response.

**References:**

1. Title 10 CFR Part 835 (2007), "Occupational Radiation Protection" Subpart N.
2. DOE Order 151.1C (2005), "Comprehensive Emergency Management Systems".
3. (Site specific emergency preparedness manuals).

**Instructional Aides:**

1. Overheads
2. Overhead projector/screen
3. Whiteboard/chalkboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

State that most people have an attitude that "it can't happen here" and don't take incident response planning seriously. Explain that incidents do occur, and experience has shown that best response comes from workers who have prepared themselves with a plan for dealing with incidents. Relate to a car skidding on ice. If the driver has thought about corrective actions for skidding, he will be less likely to panic. State that no plan can give an exact solution to every problem, but that a step-by-step approach to responding to any problem can be used.

## C. Overview of Lesson

1. Radiological incidents
2. Response to incidents
3. Response to emergencies or potential emergencies
4. Radiological emergency planning and organizations

## D. Introduce Objectives

**II. MODULE OUTLINE**

NOTE: This lesson plan should be developed using site specific information and regulatory documents. The following is a recommended format of material.

## A. Radiological Incidents and Emergencies

1. Definition

Show O.H.:  
Objectives

Ask the student to explain the difference between an emergency and incident and define each one. Modify their answer and write the correct definition on the board.



- a. Incident
    - 1) Unplanned event involving radiation or radioactive materials (part of an emergency)
    - 2) Response governed by normal procedures
  - b. Emergencies are classified as either an Alert, Site Area Emergency, or General Emergency, in order of increasing severity, when events occur that represent a specific threat to workers and the public due to the release or potential release of significant quantities of radiological and non-radiological hazardous materials. Classification aids in the rapid communication of critical information and the initiation of appropriate time-urgent emergency response actions.
  - c. Operational Emergencies are major unplanned or abnormal events or conditions that: involve or affect DOE/NNSA facilities and activities by causing or having the potential to cause serious health and safety or environmental impacts; require resources from outside the immediate/affected area or local event scene to supplement the initial response; and, require time-urgent notifications to initiate response activities at locations beyond the event scene. In general, to be considered an Operational Emergency, an event or condition involving the uncontrolled release of a hazardous material must: immediately threaten or endanger personnel who are in close proximity of the event; have the potential for dispersal beyond the immediate vicinity of the release in quantities that threaten the health and safety of onsite personnel or the public in collocated facilities, activities, and/or offsite; and have a potential rate of dispersal sufficient to require a time-urgent response to implement protective actions for workers and the public. Each DOE/NNSA site/facility must classify Operational Emergencies as either an Alert, Site Area Emergency, or General Emergency, in order of increasing severity, when events occur that represent a specific threat to workers and the public due to the release or potential release of significant quantities of hazardous materials from DOE/NNSA facilities/activities/operations. Classification aids in the rapid communication of critical information and the initiation of appropriate time-urgent emergency response actions.
2. Causes
    - a. Ignorance
    - b. Forgetfulness

- c. Oversight
- d. Unforeseen circumstances
- e. Communications failures
- f. Mechanical failures
- g. Human error
- h. Natural disasters

3. Examples

*(Insert site specific information here)*

Ask the student for causes of incidents. List these on the board.

Ask the student for examples of potential incidents at the site. List these on the board and relate to causes.

Ensure that all of the basic incident types described in the site accident analysis are included in the discussion.

- a. Ignorance - Inexperienced operator not knowing correct procedure and opens the wrong valve. For each general type of incident:
  - b. Oversight - Misreading an indicator and allowing a valve to be opened.
    - Discuss expected radiation levels and/or types and quantities of isotopes released
  - c. Mechanical Failure - Instrument line ruptures causing spread of contamination.
    - Discuss on site consequences
    - Discuss off site consequences
    - Ask the student for examples of how human error or violating procedures could result in the consequences of the incident being greater than presented in the site accident analysis.
4. Non-radiological risks
- B. General Response to Emergencies
1. Although radiological control personnel respond to an emergency using basic guidelines, an area or site may have specific procedures which have priority over these guidelines.
  2. Radiological control personnel must be familiar with the emergency procedures applicable to each site and the types of equipment to which they are assigned. The basic guidelines can then be used in conjunction with the specific procedures. In addition, the order or necessity of some actions may change depending on whether one is the first responder, one of many responders, or a backup person.
  3. The basic emergency response guidelines are:

Explain that immediate threats to life and health, such as fire, may require disregarding normal procedures, but that ALARA can always be applied if not following normal procedures.

Objective 2.13.01

- a. Define and assess the problem. Typically personnel at the scene are a good source of information, however remote instrumentation and other resources should not be overlooked. Depending on the nature of the incident, do not delay or over analyze the situation. Assess only what is needed for action.
- b. Attempt to stop the cause of the emergency. No undue risks should be taken.
- c. Notify site management and safety.
- d. Warn personnel in the area of the emergency. This keeps unnecessary personnel away from the event site, minimizing their exposure.
- e. Isolate the area. Install barriers as quickly as possible to establish an exclusion area. The exclusion area may be very large initially. In determining the size of the exclusion area, consider internal and external exposure rates, potential for criticality, possible spread of radioactive contamination or other hazardous materials, weather conditions, non-radiological hazards, and security (site security may assist in establishing boundaries). Outside the exclusion area normal operations may continue. Even if there is no radiological risk, an RCT may help others provide access control.
- f. Minimize personnel exposure. During initial response remember to use ALARA concepts, as practical. Plan supplementary operations as necessary to assure personnel exposure is minimized. All planned exposures above the occupational limits (5 rem) is voluntary. The following guidelines for control of emergency exposures are
  - 1) Up to 10 rem for protecting major property and where lower dose limit is not practicable

Whether or not to activate a site emergency response program (such as dialing 911) is determined by the nature of the incident. Activation usually automatically fulfills this requirement. When a situation is confusing, not fully understood, or may not be controllable; over reacting is better than under reacting.

- 2) Up to 25 rem for lifesaving or protection of large populations where lower dose limit is not practicable
- 3) Above 25 rem for lifesaving or protection of large populations. Only on a voluntary basis to personnel fully aware of the risks involved
- g. Secure ventilation. Close entrances, windows, and the supply ventilation systems as necessary. Unless one is certain that ventilation is contributing to the incident, this may involve no more than just ensuring that conditions are correct for normal designed ventilation.
- h. Perform surveys. Radiological control personnel are trained to perform emergency surveys. Types of surveys will vary with the nature of the emergency. Performing good surveys may require significant time but must be done before recovery can be initiated.
- i. Initiate the recovery. This includes clean-up operations, decontamination and moving the exclusion area barricade inward.

### C. Facilities and Equipment

Objective 2.13.02

#### 1. Facilities

RCTs should have a thorough knowledge and understanding of processes and hazards of their assigned facility. This should include a knowledge of the *Site Emergency Response Plan*. These plans usually contain information concerning evacuation routes, staging areas, handling of contaminated personnel, and information concerning off-site support organizations.

#### 2. Equipment

Typically, facilities maintain "emergency kits/cabinets" which contain supplies used in responding to emergencies. These kits/cabinets usually contain smears, gloves, bags, supplies for posting, dosimetry, respiratory equipment, and a copy of facility emergency procedures.

*(Insert site specific information here)*

RCTs should always know the resources and equipment available to them in the area where they are working. For each site or area, discuss the location, security and habitability provisions, equipment and communications available.

## D. Response to Continuous Air Monitor (Cam) Alarm

Objective 2.13.03

Airborne radioactivity may be caused by a breach in a system, or resuspension of particulate radioactivity due to work evolutions such as welding, grinding, or other heavy work. Indications that an airborne contamination event is occurring include CAM alarms, air samples exceeding limits, and increasing radiation levels.

## 1. Initial Response

- a) Stop operations that may be causing airborne radioactivity
- b) Warn others to evacuate
- c) Secure unfiltered ventilation
- d) Contact line or facility management for support

## 2. Supplementary Actions (re-entry)

- a) Upon re-entry, don respiratory equipment and protective clothing based on conditions of the event
- b) Evaluate the affected area by taking an air sample, measuring radiation levels, and checking for CAM malfunction
- c) Obtain additional air samples as necessary to determine boundaries and maintain access control
- d) Identify isotope(s) to help determine problem source and protective measures
- e) Consider additional ventilation to minimize personnel exposure and reduce the need for respiratory equipment (HEPA)
- f) Measure and control surface contamination to minimize the spread of contamination
- g) Survey exhaust systems, ventilation filters, and ducts. Have decontamination performed as necessary to minimize contamination spread
- h) Evaluate the potential for internal exposure and contact facility dosimetrist for proper internal dosimetry protocol
- i) Personnel should be interviewed for information on any off-normal event which could have caused the alarm
- j) Take air samples, once operations resume, to verify that the cause of airborne activity has been corrected

*(Insert site specific information here)*

## E. Response to Personnel Contamination Monitor Alarm

### 1. Initial Response

- a. Instruct affected worker to remain in area (standfast)
- b. Report to the scene with at least portable instruments for direct surveys and smear media
- c. Perform whole body surveys (frisk) for the appropriate type of radiation (alpha and/or beta-gamma). The RCT should be careful not to contaminate self and instrumentation
- d. Take actions to minimize cross-contamination, such as covering or placing a glove over a contaminated hand

Explain the basis for and significance of the alarm setpoints for CAMs at your site

Objective 2.13.04

### 2. Supplemental Actions

- a. Survey affected area to characterize the extent of contamination
- b. Suspect an up-take if contamination is verified and survey facial area for contamination, taking nasal smears or nose blows. If positive, contact RCT supervision and refer to your facility specific procedures
- c. If contaminated, follow-up actions include saving any radioactive material pertaining to the contamination event, as this may help characterize the event at a later time.
- d. Refer to facility specific procedures if contamination persists
- e. Document all surveys and estimate skin dose on proper forms Do not unduly delay any decontamination efforts by taking too long in documenting contamination for skin dose estimates. Remember that dose is being incurred all the time that the skin is contaminated. Think ALARA especially in the case of high energy beta emitters.
- f. Report all confirmed skin contaminations to RCT supervision and refer to your facility specific procedures if transporting to a medical facility.
- g. Gather appropriate information for follow-up surveys.

3. Follow-up actions shall be in accordance with the site procedure. These typically include:

- a. Removal of contaminated clothing or decontamination of minor skin contamination. Decontaminate skin using mild non-abrasive soap and tepid water or decon towelettes. Continue decon as long as significant reduction in activity is occurring after each decon. Do not irritate the skin.
- b. Verification that personnel monitoring equipment is working properly. Equipment should not be returned to service until all problems are resolved. Alarms can be caused by a variety of equipment failures or by "nuisance" non-work related situations such as environmental radon resulting from local conditions.

*(Insert site specific information here)*

#### F. Response to Off-scale or Lost Dosimetry

1. For Off-scale self reading dosimeters, typical actions include:
  - a. Assure that the worker is placed in as safe an area as possible (low dose area) and that the work has been left in a safe condition where possible.
  - b. Alert others working in the area (for off-scale response).
  - c. Evaluate the situation. All dose indicated by the dosimeter is assumed to have been received by the individual until it can be clearly demonstrated otherwise.
  - d. Gather data for dose estimate. Data typically includes work area dose rates, work activities, worker position, co-worker dose readings, and travel path conditions. For High exposures, the official permanent dosimetry (TLD or film badge) should be retrieved for processing.
2. For lost dosimetry, typical actions include:
  - a. Individual(s) must leave the area if dosimetry is required.
  - b. Contact RCT supervision for reissue of dosimetry.

NOTE: Alarms and alarm set points should not be tampered with. If alarm cannot be silenced by the acknowledge button, take out of service.

Objective 2.13.05



3. Supplemental action
  - a. Notify workers supervision
  - b. Restrict additional entries until a dose assessment can be completed
  - c. Consider suspending further work on the RWP until issues are resolved

*(Insert site specific information here)*

G. Response to Rapidly Increasing, Unanticipated Radiation Levels or an Area Radiation Monitor Alarm.

Objective 2.13.06

1. Initial Response
  - a. Evacuate personnel as quickly as possible to a safe area (low dose area).
  - b. Measure radiation levels in affected area.
  - c. Notify line/facility management. Whether or not to activate a site emergency response program (such as dialing 911) is determined by the nature of the incident. Activation usually automatically fulfills this requirement. When a situation is confusing, not fully understood, or may not be controllable; over reacting is better than under reacting.
  - d. Evaluate the situation. The best contact is people at the scene.
  - e. Verify postings and boundaries are adequate.
2. Supplemental Actions
  - a. Verify personnel staging area dose rates are acceptable and check individual exposures. Notify RCT supervision of results.
  - b. Re-occupy area upon approval of line/facility management.
  - c. Document all surveys using appropriate forms.

*(Insert site specific information here)*

Objective 2.13.07

H. Response to Dry or Liquid Radioactive Spill of Known Material and Origin Requiring SWIMS

1. STOP the spill.
  - a. Take appropriate precautions, dependent on situation, all are different.

- b. Correct immediately, if possible without undue risks. ALARA should be practiced at all times. If a major spill can be averted with minimal risk, then some action may be warranted; otherwise, try to contain the spill as it presents itself.
2. WARN other personnel.
  - a. Let people in the affected area know what is going on.
  - b. If situation warrants, evacuate the area.
  - c. Notify your supervisor, site management, and emergency response network if appropriate. As before, whether or not to activate a site emergency response program (such as dialing 911) is determined by the nature of the incident. Activation usually automatically fulfills this requirement. When a situation is confusing, not fully understood, or may not be controllable; over reacting is better than under reacting.
3. ISOLATE the area. Use banners or whatever materials available to isolate the area. Recruit whatever personnel are at hand to assist.
  - Establish boundaries and post the area for exposure and contamination control.
4. MINIMIZE exposure. Use all protective gear available. Do not risk uptakes by not using respiratory protection or anti-contamination clothing.
  - a. To yourself as well as others.
  - b. Practice ALARA principles.
5. SECURE Ventilation
  - Control HVAC (heating, ventilation, air conditioning).
6. Supplemental actions
  - a. Survey as necessary including air sampling.
  - b. Decontaminate as necessary.
  - c. Verify boundaries.
  - d. Complete all documentation surveys and logs.

Unless one is certain that ventilation is contributing to the incident, this may involve no more than just ensuring that conditions are correct for normal designed ventilation.

Major spills may very likely involve many people and require Radiation Work Permits and ALARA reviews of activities. Do not try to clean up a major spill by yourself, just keep it contained and isolated until the entire clean up operation is formulated.

*(Insert site specific information here)*

7. If you cannot contain the spill or are unaware of the spill's nature, use WIN
  - a. Warn others
  - b. Isolate the area
  - c. Notify

#### I. Response to a Fire in a Radiological Area or Involving Radioactive Materials

Typically Radiological Control will supply support to the Fire Department and will be represented at the Command Post. Additional actions could include the following.

1. Assist in evacuation of personnel.
2. Perform air samples, radiation, and contamination surveys.
3. Establish radiological boundaries.

*(Insert site specific information here)*

#### J. Response to Other Site Specific Incidents

Objective 2.13.09

*(Insert site specific information here)*

#### K. Response Levels

Objective 2.13.10

1. **ALERT.** An Alert shall be declared when events are predicted, are in progress, or have occurred that result in actual or potential substantial degradation in:
  - a) Level of control over hazardous materials
  - b) Safety or security of a nuclear weapon, component, or test device that would not pose an immediate threat to workers or the public
  - c) Safety or security of a facility or process that could, with further degradation, produce a Site Area Emergency or General Emergency
2. **Site Area Emergency.** A Site Area Emergency shall be declared when events are predicted, in progress, or have occurred that result in actual or potential situations that could include one or more of the following:

- a) Major failure of functions necessary for the protection of workers or the public
  - b) Threat to the integrity of a nuclear weapon, component, or test device that may adversely impact the health safety of workers in the immediate area, but not the public
  - c) Major degradation in level of safety or security of a facility or process that could, with further degradation, produce a General Emergency
3. General Emergency. A General Emergency shall be declared when events are predicted, in progress, or have occurred that result in actual or likely situations that could result in one or more of the following:
- a) Catastrophic reduction of facility safety or security systems with potential for the release of large quantities of hazardous materials to the environment
  - b) Catastrophic failures in safety or security systems threatening the integrity of a nuclear weapon, component, or test device that may adversely impact the health and safety of workers and the public

*(Insert site specific information here)*

#### L. Documentation of Radiological Incidents and Event Categorizations

*(Insert site specific information here)*

Objective 2.13.11

##### Event Categorizations

Significance Category 1. Occurrences in this category are those that are not Operational Emergencies and that have a significant impact on safe facility operations, worker or public safety and health, regulatory compliance, or public/business interests.

Significance Category R. Occurrences in this category are those identified as recurring, as determined from the periodic performance analysis of occurrences across a site.

Significance Category 2. Occurrences in this category are those that are not Operational Emergencies and that have a moderate impact on safe facility operations, worker or public safety and health, regulatory compliance, or public/business interests.

Significance Category 3. Occurrences in this category are those that are not Operational Emergencies and that have a minor impact on safe facility operations, worker or public safety and health, regulatory compliance, or public/business interests

Significance Category 4. Occurrences in this category are those that are not Operational Emergencies and that have some impact on safe facility operations, worker or public safety and health, public/business interests.

#### M. Emergency Response Organization

*(Insert site specific information here)*

Emergency organization and responsibilities may include:

1. Site specific teams
2. Crisis Manager
3. Crisis Management Team
4. Operational Assistance Team
5. Emergency Response Team
6. First Line Initial Response Team

Discuss reporting and authority relationships, persons normally assigned to each team, and where they are located. Emphasize the responsibilities of RCT when assigned to applicable teams.

#### N. Offsite Support Groups

*(Insert site specific information here)*

1. Purpose is to overcome the limitations of the lack of training and insufficient equipment/personnel.
2. May include:
  - a. Firefighting
  - b. Medical
  - c. Law enforcement
  - d. Radiological Assistance Program (RAP) Team

#### Objective 2.13.13

For each offsite support group, discuss the training and qualifications, number of personnel, and equipment resources available.

Explain that local offsite response groups may have different dose guidelines that they have to follow. Emphasize that the most restrictive guideline must be followed for these personnel.

#### Objective 2.13.14

#### O. Site Specific Lessons Learned

*(Insert site specific information here)*

Ensure that all of the basic incident types at the site are included in the discussion. For each of the following incidents, refer the students to the applicable site procedures listed and discuss each step. Emphasize the rationale for the actions instead of just listing them. Include each of the following under the discussion of each incident type as applicable:

- Additional ways in which each could be discovered, such as routine surveys or observation of unusual conditions.
- Who is in charge of response
- Radiation Control responsibilities
- Immediate actions
- Corrective actions
- Recovery
- Documentation

Read the accident reports and analysis and then:

- Discuss the radiation levels and/or types and

**III. SUMMARY**

## A. Review major points

1. Radiological incidents
2. Response to incidents
3. Response to emergencies or potential emergencies
4. Radiological emergencies planning and organizations

## B. Review learning objectives

**IV. EVALUATION**

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.

- quantities of isotopes released.
- Discuss on site consequences.  
Discuss off site consequences.

Conduct summary by asking questions which will show that the student objectives have been met. Modify answers for completeness, correctness and clarity. Use the student objectives to formulate your questions. Base your selection of questions on the areas that the students have demonstrated some weakness or misconceptions.

**Course Title:** Radiological Control Technician  
**Module Title:** Personnel Decontamination  
**Module Number:** 2.14

**Objectives:**

- 2.14.01 List the three factors which determine the actions taken in decontamination of personnel.
- 2.14.02 List the preliminary actions and notifications required by the RCT for an individual suspected to be contaminated.
- 2.14.03 List the actions to be taken by the RCT when contamination of clothing is confirmed.
- 2.14.04 List the actions to be taken by the RCT when skin contamination is confirmed.
- 2.14.05 List the steps for using decontamination reagents to decontaminate personnel.

**References:** (Site Specific).

**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned



**I. MODULE INTRODUCTION**

## A. Self Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

In our work environment, one of the major concerns of radiological protection is the prevention of personnel contamination. When personnel contamination has been identified, it is the responsibility of RCTs to control or oversee the decontamination of the individual using the best method available.

## C. Overview of Lesson

1. Personnel decontamination
2. Basic factors
3. Suspected personnel contamination
4. Contaminated clothing
5. Skin contamination
6. Documentation
7. Decontamination reagents

## D. Introduce Objectives

Show O.H.: Objectives

**II. MODULE OUTLINE**

## A. Personnel Contamination

## 1. Monitoring

The potential for personnel contamination, either external or internal, is normally identified through one of five monitoring methods:

- a. Hand Held Count Rate Meters: external
  - b. Personnel Contamination Monitors: external
  - c. Partial Body Monitors: external
  - d. Whole Body Counts: internal (In-Vivo)
  - e. Excreta Analysis: internal (In-Vitro)
2. Work conditions

In some cases the presence of contamination is assumed prior to personnel monitoring

- a. Exposure of individual to known contaminated liquid
- b. Exposure of individual to airborne contamination without proper protection devices
- c. Improper work practices within contamination area
  - 1) Improper removal of protective clothing or devices
  - 2) Improper work practices with contaminated material
  - 3) Failure to follow the radiological control requirements set for work performed
  - 4) Unknowingly working with material discovered to be contaminated

#### B. Basic Factors

Objective 2.14.01

Once Health Physics has knowledge of potential contamination to an individual, the actions taken by the RCT will be controlled by three basic radiological control factors.

1. Physical condition of worker
  2. Location of contamination on worker
  3. Activity of nuclide(s) present
1. Physical condition

The primary concern is the physical condition of the individual. All actions will be determined by the present condition of the individual.

- a. Is the individual free from any known injury?
  - b. If an injury has occurred, identify conditions.
2. Location of contamination

Once the physical condition of the individual has been identified, the location of the contamination must be determined

- a. Is the contamination localized on the general skin surface?
  - b. Is the contamination located at body orifice or is a body orifice in close proximity?
  - c. Is the contamination located in or around a break in the skin structure of the individual?
    - 1) Abrasions
    - 2) Punctures
    - 3) Lacerations
  - d. Is there any type of skin condition present in the vicinity of the contamination?
  - e. Is the contamination on the clothing of the individual?
3. Activity and type of nuclides

The activity of the contamination must be determined as well as the type of nuclides present

- a. What is the beta-gamma activity of the nuclides present?
  - b. What is the alpha activity of the nuclides present?
- C. Preliminary RCT Actions for Personnel with Suspected Contamination

Objective 2.14.02

Upon notification of a potential personnel contamination, the initial actions taken are established by procedure.

See DOE RCS Art. 541

*(Insert site specific material here)*

Typical actions include:

1. Obtain instruments and proceed to location.

2. Assess conditions
  - a. Make necessary notifications in case of injury.
  - b. Survey for quick indication of contamination levels and location.
  - c. Ask questions about potential contamination event.
  - d. Assess need to notify RC to request support.
  - e. Remove levels of contamination immediately on skin or clothing. Retain removed contamination for dose assessment by Dosimetry.
3. Perform a detailed, whole body survey of exposed surfaces (PCs, personal clothing and/or skin), for both alpha and beta-gamma contamination. Starting at the head and proceeding to the feet, pay particular attention to the following areas:
  - contaminated area (if known)
  - nose and mouth
  - hands
  - skin folds
  - buttocks
  - knees
  - feet
  - a. Verify that the instrument is in service (e.g., turn the monitor on, check the battery, source response, and calibration) set it to the proper scale and adjust the audio output so it can be heard during the survey.
  - b. Hold the probe less than 1/2 inch from the surface being surveyed for beta and gamma contamination, approximately 1/4 inch for alpha contamination. Do not touch the area being surveyed with the probe to preclude contaminating the probe.
  - c. Move the probe slowly (approximately 2 inches per second) over the surface.
  - d. If the count rate increases during the survey, pause for 5 to 10 seconds over the area to provide adequate time for instrument response.

- e. If the count rate increases to a value greater than a pre-established contamination limit or the instrument alarms, presence of contamination is confirmed. If contamination is confirmed, remain in the area and notify radiological control personnel.
  - f. The whole body survey should take several minutes. Do not hurry the survey and survey all areas that could be contaminated.
4. If the following conditions exist, contact RC supervision and Medical personnel as appropriate:
    - a. Extensive whole body contamination
    - b. An uptake is possible because facial contamination is present
  5. If the contaminated individual must be moved to another location (e.g. hospital or decontamination facility), contain the contamination as much as possible before allowing the person to move by:
    - a. Removing and bagging shoes and/or covering feet with plastic shoe covers/booties.
    - b. Covering the hands of the individual with gloves, preferably "Surgical" gloves.
    - c. Donning a clean set of Anti-C's over contaminated clothes or merely wrapping the individual with any covering.

#### D. Contaminated Clothing

When the clothing of an individual is found contaminated, advise the individual to refrain from moving around or touching the contaminated area and follow the specified procedures for decontamination.

*(Insert site specific material here)*

Typical actions include:

1. Contain and remove areas of gross contamination including hot particles by pulling off with tape or cutting out the area and securely bagging the contamination.

#### Objective 2.14.03

Note: Clothing contamination should be treated just as seriously as skin contamination until the clothing has been removed and it has been verified that no skin contamination is present.

2. Carefully remove and securely bag all contaminated clothing. Properly store and save the contaminated clothing worn by the individual for analysis by dosimetry if there is skin contamination or a possible uptake of radioactive material.
3. Perform a personnel whole body survey after removal of contaminated clothing to determine that the individual is not recontaminated.
  - a. If contamination persists consider moving to a decontamination facility.
  - b. Assess potential for internal deposition (airborne, puncture) by surveying outside and inside of masks, surveying facial area, and taking mouth or nasal smears.

#### E. Skin Decontamination

When the skin of an individual is found contaminated, follow the specified procedures for decontamination.

*(Insert site specific material here)*

Typical actions include:

1. Immediately remove hot particles and other high levels of contamination. The time spent to determine the activity and area of contamination should be minimized when high doses are possible.
2. Notify the RC supervisor or designated facility contact.
3. Determine the condition of the skin (cuts, sores, abrasions, irritations, etc.) and decontaminate if appropriate.
  - a. Treatment of contaminated skin with skin conditions (including wounds) is usually reserved for medical personnel. Flushing minor wounds with plain tepid water may be permitted.
  - b. Whole skin can be decontaminated by wiping with moist towlettes, flushing with plain tepid water, or washing with mild non abrasive soap and tepid water. Tape should only be used in areas where there is minimal hair and hair can only be trimmed with permission of the individual.
  - c. Retain particles or other samples of contamination for analysis and dose assessment by Dosimetry.

#### Objective 2.14.04

Note: Stop the decontamination effort if the skin becomes irritated or the individual complains of discomfort.

- d. Assess potential for internal deposition (airborne, puncture) by surveying outside and inside of masks, surveying facial area, and taking mouth or nasal smears.

#### F. Documentation

After decontamination has been completed, it is essential that the proper documentation is completed for proper records.

*(Insert site specific material here)*

Typical documentation includes:

1. An estimate of skin area and location affected and the activity involved.
2. The decontamination process including levels and iterations.

#### G. Decontamination Reagents

Objective 2.14.05

*(Insert site specific material here)*

Typical steps in the use of decontamination techniques are:

1. Washing with mild non-abrasive soaps, flushing with plain tepid water, and sweating techniques should be used for initial decontamination. Always begin with the least irritating agents before proceeding to stronger agents. These techniques may be employed by RCTs in the field.

Note: Stop the decontamination effort if the skin becomes irritated or the individual complains of discomfort.

Sticky tapes may also be used initially as long as the potential for skin irritation is kept in mind.

2. Stronger and more abrasive soaps (Tide, Clorox, or cornmeal) may dislodge the contamination but are generally used by medical personnel because of their potential for damaging the skin.
3. Stronger chemical techniques such as those using Potassium Permanganate ( $\text{KMnO}_4$ ), Sodium Bisulfite ( $\text{NaHSO}_3$ ), DTPA (as a wash), or CaDTPA (as a wash) are not often needed, but when they are, they should be used only by trained medical personnel.

**III. SUMMARY**

- A. Review major points
  - 1. Personnel decontamination
  - 2. Basic factors
  - 3. Suspected personnel contamination
  - 4. Contaminated clothing
  - 5. Skin contamination
  - 6. Documentation
  - 7. Decontamination reagents
- B. Review learning objectives

**IV. EVALUATION**

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.



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**Course Number:** Radiological Control Technicians  
**Module Title:** Radiological Considerations for First Aid  
**Module Number:** 2.15

**Objectives:**

- 2.15.01 List the proper steps for the treatment of minor injuries occurring in various radiological areas.
- 2.15.02 List the requirements for responding to major injuries or illnesses in radiological areas.
- 2.15.03 State the RCT's responsibility at the scene of a major injury in a radiological area after medical personnel have arrived at the scene.
- 2.15.04 List the requirements for treatment and transport of contaminated injured personnel at your facility.

∴

- 1. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5<sup>th</sup> ed.; Pacific Radiation Corporation; 2008.
- 2. Operational Health Physics Training - H. J. Moe

**Instructional Aids:**

- 1. Overheads
- 2. Overhead projector/screen
- 3. Whiteboard/chalkboard
- 4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

Injuries occurring in radiological areas, particularly in contaminated, airborne, or areas with high radiation dose rates require special considerations above and beyond standard first aid. The RCT may often be the first person or one of the first, to arrive at the scene of an injury. Because of this, the RCT must know how first aid requirements and radiological control requirements may conflict and on what basis to establish priorities. This lesson will introduce the special considerations for injuries in radiological areas.

There is no way possible to prepare and train for all possible injuries and radiological condition combinations. It is incumbent on the RCT to use his or her knowledge and training to make judgement calls based on available facts and conditions. Often there is more than one "right way" to handle the situation, with many alternatives which may all work equally well.

## C. Overview of Lesson

1. Minor injuries occurring in radiological areas
  2. Major injuries occurring in radiological areas
  3. Interface of RCT with medical personnel
  4. RCT responsibilities in the treatment and transport of contaminated personnel

## D. Introduce Objectives

Show O.H.: Objectives

**II. MODULE OUTLINE**

## A. First Aid

Standard first aid is applied prior to contamination control whenever it is considered to have life-saving value, or is important to the patient for relief of pain or prevention of disability. It is the obligation of all who

assist a patient to render such aid within the limits of their training and qualifications.

B. Minor Injuries Occurring in Radiological Areas

Objective 2.15.01

1. Render first aid as needed
2. Survey for contamination (clothing, skin, wounds).
  - a. Radiological Protection is responsible for determining whether wounds are contaminated, and then advise Medical.
3. Decontaminate as necessary, including area(s) around the wound(s). Do not attempt to decontaminate the wound(s).
4. Inform Medical - This information is of use in determining appropriate treatment.
  - a. Injured's name
  - b. Injured's condition
  - c. Location
  - d. Contamination levels
5. Get Medical Aid
  - a. If the person is not contaminated, the person may be escorted to the nearest First Aid Station for treatment.
  - b. If the person is contaminated, contain the contamination if possible by covering the area, and transport to the nearest personnel decon station as necessary, and medical assistance should be requested at that location

Decontamination of wounds or broken skin by RCT's is generally limited to flushing with tepid water. Complete decontamination of wounds or broken skin is generally done by Medical personnel.

Depending on the minor injury and local procedures, activation of an emergency response may be appropriate and this would provide medical aid.

## C. Major Injuries Occurring in Radiological Areas

Objective 2.15.02

1. If first to arrive on the scene:
  - a. administer first aid
  - b. get help to the scene
  - c. survey injured person(s)
  - d. assist Medical personnel
  
2. Administer first aid. The first consideration is getting appropriate medical treatment to the patient, either in the radiological area or through evacuation from the radiological area. This should be considered prior to first aid measures **only** if leaving the person in the area for a short time would further endanger the injured's and rescuer's health and safety.
  - a. Contamination levels would almost never be cause for immediately evacuating, or delaying first aid to, a seriously injured person from an area **prior** to first aid.
    - 1) A contaminated live person is, in every case, preferable to a clean deceased person.
    - 2) If the person administering first aid becomes contaminated, remember that the rescuer can be decontaminated much easier than the injured person can be brought back to life if first aid was delayed to enable the rescuer to avoid becoming contaminated.
  - b. Airborne radioactivity would almost never be cause for immediately evacuating, or delaying first aid to, a seriously injured person from an area **prior** to first aid.
    - 1) Remember that a live patient with some internal contamination is always preferable to a deceased person with no internal contamination.
  - c. Radiation levels **could** require evacuation to be the first consideration.

Ask students: "What contamination level, if any, would require evacuation prior to treatment?"

Ask students: "What if person needs CPR and has facial contamination?"

Ask students: "Would there ever be an airborne level high enough to warrant evacuation prior to first aid?"

Ask students what radiation levels they think would require movement prior to first aid.

- 1) Consideration must be given to both the injured and the rescuer(s) in this instance.
  - 2) If treating the person in the location would expose them or the rescuer(s) to a hazardous radiation dose, movement out of the area would then be done first.
  - 3) This is a judgement call, depending upon the nature of the injuries, the radiological conditions, the location of the injured, etc. There is no "magic number" for a dose rate that would require immediate movement regardless of injury.
3. Get help to the scene. The timing and method of doing this will depend on the extent of the injuries, the location, how many people are present, etc.
  4. Survey the injured person(s). This should include the clothing, exposed skin, and any wounds.
    - a. If the injured is in an area with high radiation levels, the RCT must be able to provide an estimated equivalent dose to Medical. Even if the levels are not high enough to warrant immediate evacuation, the total dose to the injured individual may dictate what medical treatment is given. This would require a knowledge of the radiation dose rates in the area, and determination (or estimate) of the length of time that the person was exposed to these levels.
  5. Assist Medical personnel with treatment, transportation, and decontamination.
    - a. For a seriously injured and contaminated person, transportation would be by ambulance.
    - b. For transport of contaminated person(s), the RCT would accompany the injured in the ambulance.
      - 1) Necessary measures should be taken to reduce or eliminate the spread of contamination on the way.

e.g., A person has an injury with severe bleeding in a very high radiation area, receives treatment and recovers, but received in excess of 400 rems whole body radiation. What is the primary long term medical concern?

Decontamination or even the purchase of a new ambulance is far easier and cheaper than bringing someone back to life.

- 2) If the patient has gross transferable contamination, consideration should be given to wrapping the injured person in a blanket to contain the contamination. Since this could prevent or delay treatment, or in some cases aggravate the injuries, it would only be done with the concurrence of Medical personnel.
- c. Control movement of personnel between rooms at the medical facility to prevent the spread of contamination.
- d. Provide containers and instruct patients regarding the collection of bioassay samples. Collect specimens of any blood, excised tissue, etc.
- e. Survey all clothing, equipment and instruments used in the transport vehicle, recommend decontamination or disposal of items as necessary.
- f. Some typical problems and concerns arising in hospital situations:
  - 1) Portable X-ray machines, as soon as the X-ray has been taken, the hospital staff will usually want to remove the machine from the room ASAP.
  - 2) Waste and contaminated materials removed from the patient may begin to pose a radiation hazard if allowed to concentrate or remain in the immediate vicinity. Also will increase background levels.

#### D. Interface of RCT and Medical Personnel

1. After the initial response and first aid, the primary duty of the RCT will be with radiological concerns. The primary concern of Medical personnel will be the patients' medical condition and treatment. These two concerns must be balanced against one another keeping the best interest of the patient in mind. RCTs are not doctors; doctors and nurses are usually not qualified RCT personnel.
2. The RCT must be careful **not** to make medical decisions or judgments that he/she is not qualified to make. The RCT **will** be primarily responsible for decisions involving radiological concerns.

Examples:

- a. A person has a piece of metal sticking out of her arm. The bleeding has been slowed so that it is not life threatening.

Objective 2.15.03

Encourage a discussion of this scenario with the class and illustrate the range of opinions.

The piece of metal has contact radiation levels of 10 rad/hr  $\beta$  and 5 R/hr gamma. The medical personnel arriving at the scene ask you "Should we remove the piece of metal prior to transporting the patient?" What do you tell them?

- b. A person has fallen off of a ladder and is unconscious. There are no outward signs of serious injury. The person is breathing and has a pulse. The immediate area has a neutron whole body radiation level of 15 rems/hr. You had a medical person arrive at the scene at the same time. Upon learning of the radiation level, the medical person asks if he should immediately move the person prior to the arrival at the scene of a stretcher or more personnel. How do you respond?
3. The RCT should advise medical personnel of radiological conditions and precautions and make decisions concerning the radiological protection of personnel on the scene.
- E. Requirements for the Treatment and Transport of Contaminated Injured Personnel

Encourage classroom discussion of this scenario, emphasizing that there are an infinite number of possible injury/radiological scenario combinations.

Objective 2.15.04

*(Insert site specific material here.)*

### III. SUMMARY

- A. Review major topics
1. Minor injuries occurring in radiological areas
  2. Major injuries occurring in radiological areas
  3. Interface of RCT with medical personnel
  4. RCT responsibilities in the treatment and transport of contaminated personnel
- B. Review learning objectives

### IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.



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**Course Title:** Radiological Control Technician  
**Module Title:** Radiation Survey Instrumentation  
**Module Number:** 2.16

**Objectives:**

- 2.16.01 List the factors which affect an RCT's selection of a portable radiation survey instrument, and identify appropriate instruments for external radiation surveys.
- 2.16.02 Identify the following features and specifications for ion chamber instruments used at your facility:
- a. Detector type
  - b. Instrument operating range
  - c. Detector shielding
  - d. Detector window
  - e. Types of radiation detected/measured
  - f. Operator-adjustable controls
  - g. Markings for detector effective center
  - h. Specific limitations/characteristics.
- 2.16.03 Identify the following features and specifications for high range instruments used at your facility:
- a. Detector type
  - b. Instrument operating range
  - c. Detector shielding
  - d. Detector window
  - e. Types of radiation detected/measured
  - f. Operator-adjustable controls
  - g. Markings for detector effective center
  - h. Specific limitations/characteristics.
- 2.16.04 Identify the following features and specifications for neutron detection and measurement instruments used at your facility:
- a. Detector type
  - b. Instrument operating range
  - c. Types of radiation detected/measured
  - d. Energy response
  - e. Operator-adjustable controls
  - f. Specific limitations/characteristics.

**References:**

1. Radiation Detection and Measurement, Glenn F. Knoll.
2. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5<sup>th</sup> ed.; Pacific Radiation Corporation; 2008.
3. Operational Health Physics, Harold J. Moe.
4. ANSI N323A.
5. (Various Manufacturers Technical Manuals).

**Instructional Aids:**

1. Overheads
2. Overhead projector and screen
3. Chalkboard/markerboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

External exposure controls used to minimize the equivalent dose to personnel are based on the data taken with portable radiation survey instruments. An understanding of these instruments is important to ensure the data obtained is accurate and appropriate for the source of radiation. This lesson contains information about widely used portable radiation survey instruments.

## C. Overview of Lesson

1. General discussion
2. Factors affecting instrument selection
3. Eberline RO-2 series
4. Bicron RSO-50 and RSO-500
5. Victoreen 450B
6. Eberline Teletector
7. Eberline RO-7
8. Eberline PNR-4 with NRD sphere
9. Eberline ASP-1 with NRD sphere

## D. Introduce Objectives

Show O.H.: Objectives

NOTE: The text is provided for some commonly used instruments. The facility must adjust text as necessary for instruments used at each site. Text added for specific instruments used at the facility must, at a minimum, cover material required by the objectives.

## II. MODULE OUTLINE

### A. General Discussion

1. Measurements using portable radiation survey instruments provide the basis for assignment of practical external exposure controls. In order to establish the proper controls, radiation measurements must be an accurate representation of the actual conditions.
2. Many factors can affect how well the measurement reflects the actual conditions, such as:
  - a. Selection of the appropriate instrument based on type and energy of radiation, radiation intensity, and other factors.
  - b. Correct operation of the instrument based on the instrument operating characteristics and limitations.
  - c. Calibration of the instrument to a known radiation field similar in type, energy and intensity to the radiation field to be measured.
  - d. Other radiological and non-radiological factors that affect the instrument response, such as radioactive gases, mixed radiation fields, humidity and temperature.

### B. Factors Affecting Instrument Selection

Objective 2.16.01

1. As discussed, the selection of the proper instrument is critical to ensure the data obtained are accurate and appropriate.
2. The instrument is selected based on the characteristics and specifications for that instrument as compared to the required measurements.
3. Several factors should be considered when selecting the instrument.
  - a. Type of data required:

Distinguish clearly between external radiation surveys (lesson 2.16) and contamination monitoring (lesson 2.17). External radiation surveys require an instrument that reads R/hr, rem/hr, etc, rather than cpm, etc.

- b. Measurement of the true equivalent dose:

Ion chambers (which read current instead of counting pulses) have the flattest energy response. Ion chambers are closest to being tissue equivalent. Generally the best choice for external beta-gamma surveys is an ion chamber.

- c. The type of radiation to be measured:

Ion chambers measure beta and gamma. For neutrons, choose a rem ball (NRD). Alphas are not measured in an external radiation survey, since they do not penetrate the skin ( $7 \text{ mg/cm}^2$ ).

- d. The intensity of the radiation (exposure or dose rate):

For high radiation fields ( $> 5 \text{ R/hr}$ ) use an extendible instrument (Teletector) if this is "reasonably achievable" (ALARA).

- e. The energy of the radiation to be measured:

low energy radiation will not penetrate either the skin, or the window of most external radiation instruments;

GM detectors over-respond to low energy gammas;

most instruments under-respond to high energy neutrons.

- f. Environmental factors:

ion chambers are usually vented to air, so radioactive gases or high humidity affect the instrument response

- g. Procedural requirements

4. Pre-operational check.

Once the proper type of instrument has been identified, a pre-operational check is essential and must be performed in accordance with appropriate procedures.

- a. Physical damage

Perform a physical inspection of the instrument by checking for obvious physical defects or damage, especially of the probe, and replace the probe or cable if necessary.

- b. Calibration

Verify the instrument is calibrated and has not exceeded the calibration due date.

## c. Battery

Perform a battery check to verify the battery condition is within the acceptable range. Change the batteries if necessary.

## d. Zero

Perform a zero adjustment for the meter needle, if applicable.

## e. Source check

Perform a source response check as required by procedures.

5. To ensure the proper selection and operation of instruments, the instrument operator must understand the operating characteristics and limitations of each instrument available for use.

The following general principles apply to each of the specific instruments described in later sections.

## a. Detector type.

Ion chambers have the flattest energy response. Ion chambers are closest to being tissue equivalent.

GM detectors over-respond to low energy gammas.

Special detectors are used for neutrons.

## b. Operating range.

External radiation measuring instruments read in R/hr, rad/hr, or rem/hr. In contrast, instruments designed for measuring contamination read in cpm.

Extendible instruments are generally appropriate for high radiation fields.

## c. Detector shielding.

Large amounts of shielding are not practical with a portable instrument, but some probes incorporate a small amount of shielding to reduce background.

Many external radiation survey instruments incorporate a sliding "beta shield". Note that this also shields low energy gammas.

## d. Detector window.

External radiation instruments generally have windows that are about as thick as human skin ( $7 \text{ mg/cm}^2$ ). The reason for this is: if the radiation does not penetrate this window then it does not penetrate skin, and so it does not contribute any external dose.

In contrast, contamination monitoring instruments have thinner windows.

## e. Types of radiation detected/measured.

Ion chambers have a flat energy response for gammas. Ion chambers are closest to being tissue equivalent. They are also good for betas, but a correction factor may be needed.

Tube shaped GM detectors are designed so that the walls are close to the detector gas. Gamma interactions in the walls are important. A well designed detector wall can partially compensate for the over-response to low energy gammas. They are designed primarily for gammas, and also measure betas if the window is not too thick.

Pancake shaped GM detectors have side walls separated from the gas. They are good for betas, but have a low efficiency for gammas because very few gammas hit the side walls.

Gas proportional detectors distinguish between alphas and betas. They often discriminate against (reject) betas and gammas.

ZnS scintillation detectors only detect alphas.

NaI scintillation detectors are generally used for gammas.

Neutron detectors are very specialized.

## f. Operator adjustable controls.

Portable instruments generally have a battery check.

Ion chambers generally have a zero adjustment.

## g. Markings for effective detector center.

External radiation surveys are generally taken at 30 cm (except for transportation, see lesson 2.12) It is not always obvious what point on the detector should be 30 cm from the source, so most detectors mark the effective center.



- 1) The effective center of the detector, as defined in ANSI N323, is the point within the detector that produces, for a given set of irradiation conditions, an instrument response equivalent to that which would be produced if the entire detector were located at that point.
- 2) The effective center can be thought of as the point in the detector where the measurement of the radiation intensity is taken.
- 3) Portable radiation survey instruments are calibrated in a uniform field of radiation larger than the volume of the detector, so that the same radiation intensity is seen throughout the detector.
- 4) Therefore, the reading "taken" at the effective center represents the rate value in all portions of the detector.
- 5) If the radiation field over the whole detector is not uniform (such as from surface contamination, radiation streaming, or from a small point source) the exposure rate will not be uniform over the entire detector volume.
- 6) For non-uniformly irradiated detectors, the displayed value, as "taken" at the effective center, will not reflect the actual exposure rate value and a correction factor may be needed.

Objective 2.16.02

## C. Eberline RO-2 Series Instruments

1. The Eberline RO-2, RO3 series of instruments are portable, air-vented ion chamber instruments used to detect and measure gamma, X-ray, and beta radiation.

Show actual instruments

Technical specifications for the RO-3 are similar to the RO-2.

## 2. Detector

- a. Operated as an ionization chamber
- b. A phenolic, or plastic, cylinder of 3 in. diameter and 12.7 in<sup>3</sup> (208 cm<sup>3</sup>) volume with one end open but covered by a Mylar window)
- c. Fill gas - air (vented to atmosphere through a desiccant pack)
- d. The ion chamber detector is closer to tissue-equivalent than most types, allowing the instrument to accurately access the exposure rate to human tissue.

Show actual detector with desiccant pack

1. The detector is approximately tissue equivalent because the materials used for construction have an effective atomic number  $Z$  close to that of tissue at 7.5.
2. Tissue equivalent implies that the detector responds the same as human soft tissue (muscle) would if placed at the same point in the radiation field.

No detector is perfectly "tissue equivalent", but a well-designed Ion chamber is close enough for most work.

- e. Although the detector is not as sensitive as a GM, it is the detector of choice for accessing exposure because of its close correlation to the energy deposited in human tissue by radiation.
3. The RO-2 series instruments are operated in the current mode, or the mode that averages the individual pulse heights per unit time.
    - a. Individual pulse information is lost; therefore, the electrical signal will not supply information about the type and energy of the individual radiation interactions.
    - b. However, small pulses, which would be lost in the pulse mode, are averaged along with the other interactions.
  4. The instrument range of the Model RO-2 is 0 to 5000 mR/hr.

The readings are expressed in R since the measurement is made in air.

The settings are as follows:

RO-2 Ranges:  
 0-5 mR/hr  
 0-50 mR/hr  
 0-500 mR/hr  
 0-5,000 mR/hr

5. The sliding beta shield is made of phenolic as follows:
  - RO-2 shield:  $400 \text{ mg/cm}^2$  (1/8 inch) mounted on case.
  - The active volume of the detector is shielded from the side by the detector wall and the instrument case, and from the bottom by the movable beta shield and two layers of windows.
  - Detector wall is  $200 \text{ mg/cm}^2$  and the 0.13 cm aluminum case is about  $345 \text{ mg/cm}^2$ .

Review the concept of density-thickness if necessary

6. The materials and density-thickness value of the two windows, one on the case and one on the detector, for the Model RO-2 and RO3 are as follows:
  - RO-2 windows: 7 mg/cm<sup>2</sup> total, two Mylar windows of 3.5 mg/cm<sup>2</sup> each.
  - RO-3 windows: 3.5 mg/cm<sup>2</sup> total, one window of 1 mil Mylar.
7. The Model RO-2 instrument is designed to measure gamma, x-ray, and beta radiation but will detect (not measure) fast neutron radiation.
  - a. The instruments will read approximately 10%, in mR/hr, of the true neutron field, in mrem/hr.
  - b. Although an ionization chamber would respond to alpha radiation, the Mylar windows and the air gap between the two windows eliminates any possibility of an alpha response.
8. The energy response for the Model RO-2 is as follows:
  - a. Measures photon radiation within  $\pm 20\%$  for photon energies from 12 keV to 7 MeV (beta shield open). The minimum energy increases to 25 keV if the shield is closed, and to about 40 keV through the side of the instrument. Because of the thinner window, the RO3 measures photons from 8 keV.
  - b. Measures beta radiation  $>70$  keV with the beta shield open. A beta factor may be appropriate for some situations.
9. Operator-adjustable controls
  - a. RO-2 range switch with OFF, ZERO, and BATT checking positions.
    - 1) Switch ranges labeled as 5, 50, 500, and 5,000
    - 2) ZERO position works in conjunction with ZERO knob to electronically zero the meter.
    - 3) BAT1 and BAT2 positions check the two batteries used to power the instrument circuitry.
    - 4) OFF position turns the instrument off.

Show controls on the instrument

NOTE: Mechanical zero is adjusted using screw on meter face when the instrument is off and should have been adjusted at the last calibration.

NOTE: The third battery in the instrument supplies the detector bias, which is minimal and does not have a battery check position.

10. The effective center markings on the RO-2 are the "dimples" or depressions on the sides and front of the instrument case.
11. Specific limitations/characteristics
  - a. The response time for the RO-2 series of instruments is 5 seconds to reach 90% of the full value.
  - b. Geotropism, or the effect of gravity on the instrument, causes no greater than a  $\pm 2\%$  of full scale change from the actual value.
  - c. Correction factors may be needed when the radiation field is not uniform over the entire detector.
  - d. High humidity or moisture can cause leakage currents in the detector and cause erratic meter readings.
    - 1) The detector is vented through a silica gel desiccant, or drying medium, contained in a plastic box.
    - 2) The desiccant can become saturated and will need replacement if the crystals start to turn clear or pink instead of the normal blue color.
  - e. The detector is vented to atmosphere; therefore, any change in atmospheric density changes the air density in the detector.
    - 1) An increase in temperature will lower the air density in the detector and cause a lower response.
    - 2) An increase in atmospheric pressure will cause an increase in air density in the detector and cause a higher response.
    - 3) Tables are provided in the technical manuals for correcting the instrument response due to changes in pressure or temperature.
    - 4) A change in response of about 10% will occur if the instrument was calibrated at room temperature and used in an environment that is different by about 50 EF.
  - f. Because the detector is vented to atmosphere, radioactive gases can enter the detector and cause a reading.

Show markings on the instrument

#### D. Bicron RSO-50 and RSO-500 Instruments

1. The Bicron RSO-50 and RSO-500 instruments are portable air-vented ion chamber instruments used to detect and measure gamma, x-ray, and beta radiation.

Show instruments.

2. The Bicon RSO series of instruments are very similar in design and construction to the Eberline RO-2 series of instruments.
3. Detector (identical for both models)
  - a. Operated as an ionization chamber
  - b. A phenolic, or plastic, cylinder of 3 in. diameter and 12.7 in<sup>3</sup> (208 cm<sup>3</sup>) volume with one end open but covered by a Mylar window.
  - c. Fill gas - air (vented to atmosphere through a silica gel desiccant pack)
4. The Bicon RSO series instruments are operated in the current mode, or the mode that averages the individual pulse heights per unit time.
5. The instrument ranges of the two models are as follows:
  - a. RSO-500 Ranges:
    - 0-0.5 R/hr
    - 0-5 R/hr
    - 0-50 R/hr
    - 0-500 R/hr
  - b. RSO-50 Ranges:
    - 0-50 mR/hr
    - 0-500 mR/hr
    - 0-5 R/hr
    - 0-50 R/hr
6. The active volume of the detector is shielded from the side by the detector wall and the instrument case and from the bottom by the movable beta shield and two layers of windows.
  - a. Detector wall is 200 mg/cm<sup>2</sup> and the 0.13 cm aluminum case is about 345 mg/cm<sup>2</sup>.
  - b. The materials and density-thickness value of the two windows, one on the case and one on the detector, are the same for both models.
 

Show instrument windows.

    - 1) RSO windows - 7 mg/cm<sup>2</sup> total, both windows are Mylar of 3.5 mg/cm<sup>2</sup> each
  - c. The sliding beta shield is made of phenolic and the density-thickness value is the same for both models.
 

Show instrument sliding shield.

    - 1) RSO shield - 400 mg/cm<sup>2</sup> (1/8 in. thick) and is mounted externally on the case

7. The Bicron RSO series of instruments are designed to measure gamma, x-ray and beta radiation but will detect (not measure) fast neutron radiation.
  - a. The instruments will read approximately 10%, in mR/hr, of the true neutron field, in mrem/hr.
  - b. Like the Eberline RO-2, the Bicron RSO series instruments will not respond to alpha radiation because the alpha particles are shielded before they reach the detector.
8. The energy response of the two models is identical.
  - a. Both models measure photon radiation within  $\pm 20\%$  for photon energies from 12 keV to 7 MeV (beta shield open).
  - b. The minimum energy increases to 25 keV if the shield is closed, and to about 40 keV through the side of the instrument.
  - c. Both models measure beta radiation  $>70$  keV.
9. Operator-adjustable controls
  - a. RSO-500 range switch with OFF, ZERO, and BATT checking positions.
    - 1) Switch ranges labeled as 0.5, 5, 50, and 500 R/hr
    - 2) ZERO position works in conjunction with ZERO knob to electronically zero the meter.
    - 3) BAT position checks the two batteries used to power the instrument circuitry and detector bias.
    - 4) OFF position turns the instrument off.
  - b. RSO-50 range switch is the same but is labeled 50 and 500 mR/hr and 5 and 50 R/hr.
10. The effective center markings on both Bicron models are the stamped circles with a plus sign in the circle and are located on the sides and front of the instrument case.

Show markings on instrument.

If the radiation field over the whole detector is not uniform (e.g. from surface contamination, radiation streaming, or from a small point source) the displayed value may need to be corrected.
11. Specific limitations/characteristics
  - a. The response time varies between the two models of Bicron instruments available.

- 1) RSO-500 - approximately 10 seconds from 0-90% of the final reading.
- 2) RSO-50 - approximately 5 seconds from 0-90% of the final reading.
- b. Correction factors may be needed when the radiation field is not uniform over the entire detector.
- c. High humidity or moisture can cause leakage currents in the detector and cause erratic meter readings.
  - 1) The detector is vented through a desiccant, or drying medium, contained in a plastic box.
  - 2) The desiccant can become saturated and will need replacement if the crystals start to turn clear or pink.
- d. Like the Eberline RO-2, the detector is vented to atmosphere; therefore, any change in atmospheric density changes the air density in the detector.
  - 1) An increase in temperature will lower the air density in the detector and cause a lower response.
  - 2) An increase in atmospheric pressure will cause an increase in air density in the detector and cause a higher response.
  - 3) Tables are provided in the technical manuals for correcting the instrument response due to changes in pressure or temperature.
  - 4) A change in response of about 10% will occur if the instrument was calibrated at room temperature and used in an environment that is different by about 50°F.
- e. Because the detector is vented to atmosphere, radioactive gases can enter the detector and cause a reading.

#### E. Victoreen Model 450B

Show instrument.

1. The Victoreen 450B is a portable, general purpose, ion chamber survey instrument which uses microprocessor and LCD (liquid crystal display) technology.
2. Detector
  - a. Operated as an ionization chamber
  - b. A Bakelite, or plastic, cylinder of 200 cm<sup>3</sup> volume with one end open but covered by a Mylar window

- c. Fill gas - air (vented to atmosphere through a desiccant pack)
  - d. The ion chamber detector is designed as tissue-equivalent, allowing the instrument to accurately access the exposure rate to human tissue.
3. The Victoreen 450B is operated in the current mode as are most ion chambers.
  4. Instrument operating range
    - a. Overall range is 0-50 R/hr.
    - b. The instrument is auto-ranging, or automatically changes scales as required for the instrument reading, and has the following scales:
      - 1) 0-5 mR/hr
      - 2) 0-50 mR/hr
      - 3) 0-500 mR/hr
      - 4) 0-5 R/hr
      - 5) 0-50 R/hr
  5. The active volume of the detector is shielded from the side by the detector wall and the instrument case and from the bottom by the movable beta shield and windows.
    - a. Detector wall is 200 mg/cm<sup>2</sup>.
    - b. The sliding beta shield is made of Bakelite, which is a type of plastic and the density-thickness value is 440 mg/cm<sup>2</sup>.
    - c. The two detector windows, one on the detector and one on the case, are made of 1.7 mil Mylar for a total of 3.4 mg/cm<sup>2</sup>.
  6. The 450B instrument is designed to measure gamma, x-ray, beta and alpha radiation but will detect (not measure) fast neutron radiation.
    - a. The instruments will read approximately 10%, in mR/hr, of the true neutron field, in mrem/hr.
  7. Energy response
    - a. Photon energy response ( $\pm 20\%$ ) is about 20 keV for slide open, 40 keV for slide closed, and 50 keV from the side.



- b. Beta energies >32 keV can be measured. Tech manual states 100 keV; however, the minimum possible energy is 32 keV.
  - c. The alpha response is limited to energies >4 MeV and only if the detector to source distance is less than the alpha range in air. Recall that a 4 MeV alpha travels ~2.5 cm in air.
8. Operator-adjustable controls
- a. Only three external controls are available on the 450B: the ON/OFF switch, the MODE switch, and the meter light button.
  - b. The Mode switch is used during calibration and is not enabled for operator use.
  - c. The ON/OFF switch turns the instrument on and off.
    - 1) The instrument is auto-ranging and will change the bar graph, digital value, and scale markings as appropriate for the exposure rate value.
    - 2) The instrument has an "auto-zero" feature that eliminates any need for an external zero control.
    - 3) If the batteries are low, then the instrument will display a LOW BAT message.
  - d. A button switch is provided in the handle for turning the meter face light on and off.
9. The effective center markings on the 450B are the painted-white depressions in the plastic case and are located in the front and on the sides. Show markings.
10. Specific limitations/characteristics
- a. The response times to 90% of the final value for the 450B instrument are as follows, assuming that a step increase or decrease in the rate does not cause a range change:
    - 1) 0-5 mR/hr - 8 sec
    - 2) 0-50 mR/hr - 5 sec
    - 3) 0-500 mR/hr - 2 sec
    - 4) 0-5 R/hr - 2 sec
- NOTE: The response times may be greater for a step change from background to a rate value (e.g., background to 4 mR/hr - 9.3 sec).

- 5) 0-50 R/hr - 2 sec
- b. Geotropism, or the effect of gravity on the instrument, causes no greater than a  $\pm 1\%$  of full scale change from the actual value.
- c. Correction factors may be needed when the radiation field is not uniform over the entire detector, such as for surface contamination beta dose rates.
- d. High humidity or moisture could cause leakage currents in the detector and cause erratic meter readings.
  - 1) The detector is vented through a desiccant, or drying medium, contained in a plastic cylinder.
  - 2) The desiccant could become saturated and will need replacement if the crystals start to turn clear or pink.
  - 3) The atmospheric vent on the case has a rubber bladder to allow for changes in temperature and pressure but prevents the free flow of air into and out of the detector casing.
  - 4) The rubber bladder minimizes the effects of high humidity environments and radioactive gases.
- e. The detector is vented to atmosphere; therefore, any change in atmospheric density changes the air density in the detector.
  - 1) An increase in temperature will lower the air density in the detector and cause a lower response.
  - 2) An increase in atmospheric pressure will cause an increase in air density in the detector and cause a higher response.
  - 3) The value of the changes due to temperature and pressure are similar to those of other air-vented ion chambers.

#### F. Eberline Teletector

1. The Eberline Teletector is an extendable, telescoping-rod instrument designed with two Geiger-Mueller detectors for the measurement of photon exposure rates and detection of beta radiation.
2. Detectors

Objective 2.16.03

Show instrument.

NOTE: Manufactured in W. Germany and distributed in U.S. by Eberline

Detector window Show window and rubber cap.

- a. Both detectors are sealed GM tubes with halogen-quenched argon fill gas contained in an energy compensating case.
    - 1) Energy compensation is required in GM detectors to reduce the over-response to low energy photons.
  - b. The low range detector is the largest of the two detectors and is located at the end of the detector housing.
    - 1) The low range detector is used for the three lowest ranges on the instrument.
  - c. The high range detector is the small cylinder located on the offset circuit board in the detector housing.
    - 1) The high range detector is used for the upper two scales.
  - d. The GM detectors are very sensitive; however, they lack the direct correlation to energy deposited and are not as useful as ion chamber instruments for assessing exposure or exposure rates.
3. The Teletector instrument is operated in the pulse mode, or the mode that counts each individual pulse.
- a. Since any ionization in a GM tube causes the same large pulse, any radiation interaction in the detector will be counted.
  - b. All the pulses are of the same large size regardless of the energy or type of radiation; therefore, all information on the type and energy of the radiation is lost.
4. The instrument range is 0 - 1000 R/hr.

The analog Teletector has five operating ranges, each with its own meter face. The three lower ranges utilize the large GM detector and the two upper ranges utilize the smaller GM detector.

- a. 0-2 mR/hr
  - b. 0-50 mR/hr
  - c. 0-2 R/hr
  - d. 0-50 R/hr
  - e. 0-1000 R/hr
5. Detector shielding

- a. The two detectors are shielded by layers of lead and fiber to reduce the low-energy photon response.
  - b. The low-range detector has a 30 mg/cm<sup>2</sup> mica window and a rubber cap to protect the window.
6. The Eberline Teletector will measure x-ray and gamma radiation and can detect (but not measure) beta radiation.
- a. Beta response is not accurate and should be used for detection purposes only as stated in the manufacturer's instructions.
  - b. Alpha response is eliminated by the thicker window and casing.
  - c. Neutron response is insignificant due to the lower probability of interaction in the small detectors.
7. Energy response
- a. The energy response for photon radiation is 80 keV to 3 MeV ( $\pm 10\%$ ). If the detector is not pulled out of the telescoping rod housing, the minimum photon energy will be higher.
  - b. Beta particles >160 keV can be detected but not measured.
8. Operator-adjustable controls
- a. The only control is the range switch with OFF and B (battery check) positions.
  - b. Changing the range at the switch also changes the rotating meter face to the appropriate meter face for that range.
9. Detector effective center markings
- a. The effective center of both detectors is indicated by the machined grooves in the detector housing, with the groove closest to the beta window indicating the low-range detector.
  - b. The high range detector is mounted on a circuit board and is not centered in the detector housing.
    - 1) The offset is indicated by the machined groove in the housing retaining ring at the back end of the detector housing.

Mica is used on GM detectors, because Mylar would react with the halogen quench gas.

Show instrument.

- 2) Any contact readings taken using the high range detector should align the offset indicator so that it points to the source of radiation. Failure to do so will result in inconsistent readings.

#### 10. Specific limitations/characteristics

- a. Response time for the instrument is approximately 1 second to 90% of full scale.
  - b. The sealed detectors do not require correction factors for temperature or pressure.
  - c. The sealed detectors do not experience problems with humidity or radioactive gases entering the detector.
  - d. Since beta radiation is only detected and not measured, no correction factors are applied for beta radiation.
  - e. The 13 ft telescoping rod is durable but can be damaged if twisted or bent.
  - f. Audible indication is available only through the speaker jack; no internal speaker is installed.
  - g. The Eberline Teletector is non-saturating on the high ranges up to 30,000 R/hr.
- 1) For GM detectors, the possibility exists that the detectors become saturated in very high radiation fields. Some GM detector instruments will read zero if the detector becomes saturated.

#### G. Eberline RO-7

1. The RO-7 series instrument provides remote monitoring in high range beta and gamma radiation fields.
  - a. The RO-7 consists of a basic digital readout instrument, three interchangeable detectors, and various interconnecting devices.
  - b. The detectors may be interconnected to the instrument by flexible cables of different lengths, by rigid extensions of different lengths or by use of an underwater housing.
2. Detectors
  - a. All three detectors are air-vented ion chambers contained in a plastic-lined (phenolic) aluminum housing. The detector fill gas is air.

Objective 2.16.03

Show instrument.

Show detectors.

- b. The detector housing also contains other electronics, such as an operational amplifier and detector identification circuitry.
  - c. The three available detectors are as follows:
    - 1) The RO-7-LD is a low-range, gamma-only detector with an active volume of about 50 cm<sup>3</sup> and dimensions of 2.5 cm diameter and 10.2 cm long.
    - 2) The RO-7-BM is a mid-range, beta/gamma detector, with beta window, that has an active volume of about 7 cm<sup>3</sup> and dimensions of 2.5 cm diameter and 1.5 cm long.
    - 3) The RO-7-BH is a high-range, beta/gamma detector, with beta window, that has an active volume of about 7 cm<sup>3</sup> and dimensions of 2.5 cm diameter and 1.5 cm long.
  - d. Each detector is labeled at the connector end of the detector.
 

NOTE: Two small screws on the label are marked ZERO and CAL. These should only be adjusted at calibration and must not be adjusted by the operator.
3. The RO-7 instrument is operated in the current mode of operation.
  4. The operating range of the instrument is dependent on the detector that is connected to the instrument.
    - a. The range of the RO-7-LD detector is 0-2 R/hr.
    - b. The range of the RO-7-BM detector is 0-200 R/hr.
    - c. The range of the RO-7-BH detector is 0-20 kR/hr (20,000 R/hr).
  5. Detector shielding
 

All three detectors have the phenolic liner and aluminum housing.

    - a. The RO-7-BM and RO-7-BH detectors each have a 7 mg/cm<sup>2</sup> Mylar window.
    - b. The Lucite cap for the beta window is 100 mg/cm<sup>2</sup>. Show cap.
  6. Types of radiation detected/measured
    - a. As previously mentioned, the RO-7-LD detector measures only gamma and x-ray radiation.

Detector window  
Show window.

- 1) Both beta and alpha radiation are shielded by the detector housing.
- 2) Neutron radiation response is insignificant due to the small size of the detector.
- b. The actual detectors in the RO-7-BM and RO-7-BH detector assemblies are identical.
  - 1) Both detect and measure gamma, x-ray, and beta radiation.
  - 2) Alpha response is eliminated by the 7 mg/cm<sup>2</sup> window (same density thickness as the dead layer of skin).
  - 3) Neutron radiation response is even smaller than the RO-7-LD due to the smaller detector volume.
7. The energy response for the three detectors is as follows:
  - a. The RO-7-LD responds to photon radiation between 50 keV and 1.3 MeV ( $\pm 20\%$ ).
  - b. The RO-7-BM and RO-7-BH detectors respond to photon radiation differently depending on orientation and whether the Lucite cover is in place.
    - 1) Lucite cover off - 10 keV to 1.3 MeV ( $\pm 20\%$ )
    - 2) Lucite over on - 25 keV to 1.3 MeV ( $\pm 20\%$ )
    - 3) Shield on, from the side - 50 keV to 1.3 MeV ( $\pm 20\%$ )
  - c. The beta response for the RO-7-BM and RO-7-BH detectors is for beta energies  $>70$  keV.
8. Operator-adjustable controls
  - a. The ON/OFF switch is the only range control because the instrument identifies the detector model and adjusts the readout accordingly.
    - 1) A low battery condition is indicated by a "colon" under the battery mark on the meter.
  - b. The ZERO knob will zero the LCD readout.
  - c. A meter face light is turned on/off by the small switch in front of the pistol grip.
9. No markings are provided for the detector effective center.

## 10. Specific limitations/characteristics

- a. The response time of the basic instrument is 2.5 seconds to 90% of the final reading.
- b. The correction factor for the true beta measurement is 1.5 as recommended by the manufacturer.
- c. Since the detector is air-vented, atmospheric temperature and pressure changes affect the instrument reading.
  - 1) The instrument response will remain within  $\pm 10\%$  for the temperature range of -20 to 160 °F.
  - 2) A correction table is available in the technical manual for pressure changes.
- d. The detectors are air-vented but do not have a desiccant pack. The detector should be kept dry and out of high humidity environments to prevent leakage currents.
- e. Each detector has associated electronics designed for that particular range. Over-ranging a detector may cause damage to the detector electronics.
- f. If the instrument is not calibrated with the underwater housing and the housing is used, the response will be about 5% low. The instrument reading should be multiplied by 1.05 to obtain the corrected response.
- g. Interconnecting devices from the detector to the instrument that are available from the manufacturer are the:
  - 1) 15 ft flexible cable
  - 2) 60 ft flexible cable
  - 3) 2 ft rigid extension
  - 4) 5 ft rigid extension
  - 5) Stainless-steel underwater housing with 60 ft of cable

## H. Eberline NRD Neutron Sphere

1. The Eberline NRD sphere is a portable instrument for the detection and measurement of the equivalent dose rate from neutron radiation.
2. Detector

Objective 2.16.04

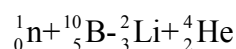
Show instrument.



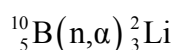
- a. The detector is the Eberline NRD (neutron radiation detector) sphere, which may be connected to the PNR-4 or to an ESP instrument by a coaxial cable.
- b. The NRD sphere is a 9 in. diameter, cadmium loaded, polyethylene sphere with a BF<sub>3</sub> proportional tube in the center of the sphere.
- c. The BF<sub>3</sub> (boron trifluoride) detector design allows the detection of only thermal neutrons because of the low probability of absorption by boron for other energy neutrons.

Show detector.

- 1) The thermal neutron capture reaction with the <sup>10</sup>B results in gas ionization pulses caused by the alpha particle product of the reaction.



or

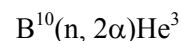


Recall thermal neutrons are defined as those neutrons with kinetic energy in thermal equilibrium with their surroundings, or 0.025 eV at STP.

- 2) Detector shielding must be employed if the detector is used for measurement of neutron energies other than thermal.

A less prominent reaction is:

### 3. Detector shielding (no window)



- a. A polyethylene sphere is used to allow assessment of the dose from fast and intermediate energy neutrons.
  - 1) The polyethylene has a high percentage of hydrogen which thermalizes the fast and intermediate energy neutrons.
  - 2) Those neutrons that are thermalized in the sphere can be detected in the BF<sub>3</sub> tube.
  - 3) The diameter of the sphere is chosen during design for the neutron energy spectrum expected to be measured.
- b. The cadmium loading is a thin, perforated sheet of cadmium surrounding the active volume of the detector and is designed to reduce the over-response of the detector to certain energy neutrons. May over-respond by 100-300% for intermediate neutrons without Cd shield.

4. Operating range
  - a. The PNR-4 has an overall range of 0-5,000 mrem/hr.
  - b. PNR-4 has a LIN-LOG meter which means the meter face is a combination of linear and logarithmic scales.
    - 1) The auto-ranging meter uses two meter needles and covers four decades (logarithmic portion).
    - 2) Within each decade of the range, the meter divisions are equally spaced (linear portion).
    - 3) The first needle covers the first two decades of 0-5 mrem/hr and 5-50 mrem/hr.
    - 4) The second needle covers the last two decades of 50-500 mrem/hr and 500-5,000 mrem/hr.
5. Types of radiation detected and measured
  - a. The instrument is designed for detection and measurement of fast and intermediate energy neutron radiation.
  - b. Alpha and beta radiation are not detected because they do not penetrate the detector shielding.
  - c. Gamma radiation passes through the detector shielding but can be rejected by the instrument circuitry up to 500 R/hr (dependent on high voltage setting and desired rejection level). At low rates, photon pulses are rejected. At high rates, pulse pile-up causes a gamma response.
  - d. Since the detector is operated in the proportional region, the pulses from the alpha particles are larger than pulses from other interactions and trigger a pulse height discriminator in the instrument circuitry.
  - e. The mode of operation for the instrument is the pulse mode so that individual pulses can be discriminated and counted.
6. Energy response for measured radiation
  - a. The instrument manufacturer states the instrument response closely follows the theoretical dose equivalent from neutrons over a range of 0.025 eV to about 10 MeV.
  - b. The instrument over-responds to intermediate energy neutrons and under-responds to relativistic neutrons.

7. Operator-adjustable controls
  - a. The only operator-adjustable control on the PNR4 is the OFF/ON/BAT switch which turns the instrument on and off and allows a check of the battery.
8. Specific limitations/characteristics
  - a. The response time depends on which decade of the scale is appropriate.
    - 1) First decade - 12 seconds
    - 2) Second decade - 6 seconds
    - 3) Third decade - 1.5 seconds
    - 4) Fourth decade - 0.3 seconds
  - b. No correction factors are necessary.
  - c. The detector is a sealed pressurized cylinder and is not affected by changes in humidity, radioactive gases or changes in atmospheric density.

#### I. Eberline ASP-1 with NRD Sphere

1. The Eberline ASP-1 with the NRD sphere is a microcomputer-based, analog-display, portable neutron radiation survey instrument.
2. The detector (Eberline NRD sphere) is identical to the detector used with the PNR-4 neutron instrument.
3. The mode of operation is the pulse mode.
4. Instrument operating ranges
  - a. The overall range is 0-100 rem/hr and has a useable range of 1 mrem/hr - 60 rem/hr per HP procedure.
    - 1) 0-1 mrem/hr
    - 2) 0-10 mrem/hr

Show instrument.

NOTE: The operating ranges are established by the calibrating facility based on the detector used and intended purpose by using interchangeable switch labels.

- 3) 0-100 mrem/hr
  - 4) 0-1,000 mrem/hr
  - 5) 0-10,000 mrem/hr
  - 6) 0-100,000 mrem/hr
5. Detector shielding is the same as previously mentioned for the NRD sphere.
  6. The energy response is the same as previously mentioned for the NRD sphere.
  7. Operator-adjustable controls
    - a. The OFF/BAT/HV/range switch has the following functions:
      - 1) The OFF position turns the instrument off.
      - 2) The BAT position checks the instrument battery power supply.
      - 3) The HV position checks the applied high voltage to the detector and should match the value listed on the special label on the instrument case.
      - 4) The range markings are X1, X10, X100, X1K, X10K, and X100K with a meter scale of 0-1.0.
    - b. The INTEGRATE/FAST/SLOW switch is a three position toggle switch with the following functions:
      - 1) In the INTEGRATE position, the instrument will show the total dose accumulated since the last time the instrument was reset to zero or turned off.
      - 2) In the FAST position, the response time selected by the microcomputer is for typical survey work.
      - 3) In the SLOW position, the response is slower but with greater accuracy than the FAST position.
    - c. The LIGHT/RESET switch is a three-position, spring-loaded toggle switch with the following functions:
      - 1) The LIGHT position illuminates the meter face.
      - 2) The RESET position will zero the meter reading for the current mode (INTEGRATE/FAST/SLOW) setting of the instrument.

- 3) The RESET switch will cause the "standard current" value to be displayed if held for 5 seconds while in the FAST or SLOW mode.
- d. The SPEAKER is a two-position toggle switch for turning the external speaker on and off.
- e. Acoustic (airline-type) head phones can be plugged into the speaker cover on the top of the instrument.
8. As previously mentioned, the NRD sphere has no effective center markings.
9. Specific limitations/characteristics
- a. The response time of the instrument is controlled by the microcomputer and is based on the input count rate and whether the mode switch is in FAST or SLOW.
    - 1) In the FAST position, the instrument response time varies between one and ten seconds.
    - 2) In the SLOW position, the instrument response time will vary up to a maximum of 29 seconds.
  - b. No correction factors are required to correct the displayed value.
  - c. The sealed detector is not affected by changes in atmospheric density, humidity or radioactive gases.
  - d. The instrument has a microcomputer controlled "over-range" indication.
    - 1) When the radiation rate exceeds the useful range of the detector, the computer will cause an over-range alarm.
    - 2) When the instrument alarms, the meter needle will sweep back and forth and an interrupted tone will sweep in the speaker.
- J. Portable Instrument Specification Chart
1. The specifications for the instruments discussed can be summarized in a chart that shows:
    - a. manufacturer
    - b. model
    - c. detector type

This is utilized as a calibration check when compared to predetermined value.

- d. operating ranges
- e. detector shield
- f. detector window
- g. radiation measured
- h. radiation detected (but not measured)
- i. response times.

### III. SUMMARY

- A. Review major points
  - 1. General discussion
  - 2. Factors affecting instrument selection
  - 3. Eberline RO-2 series
  - 4. Bicron RSO-50 and RSO-500
  - 5. Victoreen 450B
  - 6. Eberline Teletector
  - 7. Eberline RO-7
  - 8. Eberline PNR-4 with NRD sphere
  - 9. Eberline ASP-1 with NRD sphere
- B. Review learning objectives

### IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.

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**Course Title:** Radiological Control Technician  
**Module Title:** Contamination Monitoring Instrumentation  
**Module Number:** 2.17

**Objectives:**

- 2.17.01 List the factors which affects an RCT's selection of a portable contamination monitoring instrument.
- 2.17.02 Describe the following features and specifications for commonly used count rate meter probes used at your site for beta/gamma and/or alpha surveys:
- Detector type
  - Detector shielding and window
  - Types of radiation detected/measured
  - Energy response for measured radiation
  - Specific limitations/characteristics
- 2.17.03 Describe the following features and specifications for commonly used count rate instruments used at your site:
- Types of detectors available for use
  - Operator-adjustable controls
  - Specific limitations/characteristics
- 2.17.04 Describe the following features and specifications for commonly used personnel contamination monitors at your site:
- Detector type
  - Detector shielding and window
  - Types of radiation detected/measured
  - Energy response for measured radiation
  - Operator-adjustable controls
  - Specific limitations/characteristics
- 2.17.05 Describe the following features and specifications for commonly used contamination monitors used at your site (Tool, bag, laundry monitors).
- Detector type
  - Detector shielding and window
  - Types of radiation detected/measured
  - Energy response for measured radiation
  - Specific limitations/characteristics

**References:**

- Radiation Detection and Measurement, Glenn F. Knoll.
- "Basic Radiation Protection Technology"; Gollnick, Daniel; 5<sup>th</sup> ed.; Pacific Radiation Corporation; 2008.
- Operational Health Physics, Harold J. Moe.
- ANSI N323A.
- (Various Manufacturers Technical Manuals).



**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

Environmental monitoring plays a large role in the field of radiological control. Environmental monitoring is used to estimate human population doses, determine the impact a site has on the environment, monitor for unplanned releases as well as quantifying planned releases, and gives us data useful in determining pathway data.

## C. Overview of Lesson

1. Environmental monitoring goals
2. Principles of program design
3. Radiological control responsibilities
4. Analysis of environmental samples
5. Site environmental monitoring methods
6. Transport mechanisms

## D. Introduce objectives

O.H.: Objectives

**II. MODULE OUTLINE**

NOTE: The text is provided for some commonly used instruments. The site must adjust text as necessary for instruments used at each site. Text added for specific instruments used at the site must, at a minimum, cover material required by the objectives.

## A. General Discussion

1. Measurements using portable contamination monitoring (count rate) instruments provide the basis for assignment of practical contamination and internal exposure controls.

2. To establish the proper controls, the contamination measurements must be an accurate representation of the actual conditions.
3. Measurements using non-portable contamination monitors, such as an Eberline PCM-1B or PM-6 are used to identify personnel contamination prior to exiting controlled areas or facilities. Hand and shoe monitors are used by some sites.
4. Measurements using counter scalers to determine the levels of transferrable contamination on specific location samples are the basis for contamination postings and material releases from controlled areas.
5. Many factors can affect how well the measurement reflects the actual conditions, such as:
  - a. Selection of the appropriate instrument based on type and energy of radiation, radiation intensity, and other factors.
  - b. Correct operation of the instrument based on the instrument operating characteristics and limitations.
  - c. Calibration of the instrument to a known radiation field similar in type, energy and intensity to the radiation field to be measured.
  - d. Other radiological and non-radiological factors that affect the instrument response, such as radioactive gases, mixed radiation fields, humidity and temperature.

Objective 2.17.01

**B. Factors Affecting Instrument Selection**

1. The selection of the proper instrument is critical to ensure the data obtained is accurate and appropriate.
2. Instrument selection is based on the characteristics and specifications for that instrument as compared to the required measurements.
3. Several factors should be considered when selecting the instrument.
  - a. The type of radiation to be measured
  - b. The energy of the radiation to be measured
  - c. The intensity of the radiation (dose rate or activity levels)

- d. Interference from a mixed radiation field
  - e. Background radiation conditions
  - f. Environmental factors, such as radioactive gases or temperature, affecting instrument response
  - g. Procedural requirements
4. To ensure the proper selection and operation of instruments, the instrument operator must understand the operating characteristics and limitations of each instrument available for use.

Objective 2.17.02

## C. Count Rate Meter Hand Probes

## 1. EBERLINE MODEL HP-210 AND VICTOREEN MODEL 110C

- a. Models like the Eberline Model HP-210 or Victoreen Model 110C hand probes are sensitive beta detectors using a thin window "pancake" Geiger-Muller (GM) detector. These detectors are designed for contamination surveys of personnel, table tops, floors, equipment, etc.
  - 1) Detector responds to alpha, beta, gamma and x-ray radiation of minimum energies.
    - a) alpha  $>3$  MeV

Detector must be close enough to the source of alpha particles to prevent alpha particle attenuation in the air between the source and the detector.

- b) beta  $>40$  keV

This precludes the detection of low energy beta particles, such as the beta particle from the decay of tritium ( $E_{\max} = 18.6$  keV.)

- c) gamma  $>6$  keV

Photon radiation, such as gamma or x-ray, can interact in the detector walls and the fill gas to create a pulse. However, the probability of interaction is small due to the shallow depth of the detector and therefore the efficiency for photon radiation is small.

Density determines minimum energy response

- 2). GM tube has mica window of 1.4 to 2.0 mg/cm<sup>2</sup> density.
  - 3) Gamma sensitivity is approximately 3,600 counts per minute (cpm) per mR/hr for Cs<sup>137</sup>.
  - 4) Available with either high-density tungsten or aluminum housings.
    - a) HP-210AL - aluminum housing with a low shielding factor for low background use.
    - b) HP-210T - tungsten shield covering the top and sides of the detector allows use in high background area.
    - c) Victoreen 110C - aluminum housing with a low shielding factor for low background use.
  - 5) Victoreen 110C series hand probes are almost identical to the Eberline model HP-210AL.
- b. Detector type
- 1) The detector is sealed Geiger-Mueller (GM) "pancake" detector. A "pancake" detector has a radius or width that is much larger than the depth of the detector.
  - 2) The shielded hand probe contains the GM detector which has the mica window protected by a wire or stainless-steel etched screen.
  - 3) The fill gas in the GM tube is halogen-quenched argon.
  - 4) The operating voltage for the GM detector is 900V ± 50V.
  - 5) Detector has 50 μs resolving time which is defined as the minimum time that must elapse after the measurement of an ionizing particle before a second particle can be measured.
- c. Detector window and shielding
- 1) The thin detector window is 1.4 - 2.0 mg/cm<sup>2</sup> mica and is protected by the screen which is 79% open.

Weight of 1.5 lbs.

Weight of 4.5 lbs.

Halogen absorbs the UV photons from the excited positive ions without ionizing.

About midway of the voltage plateau

Dead time + recovery time = resolving time

May vary with detector type

- a) Mica windows must be used instead of Mylar, because the Mylar will react with the halogen quench gas.
  - b) The window has an effective surface area of 2.4 in<sup>2</sup> (15.5 cm<sup>2</sup>).
- d. Efficiencies for the detector are dependent on the type and energy of the radiation.
- 1) The detector is designed, calibrated and used to measure beta radiation.
    - a) 22% for <sup>137</sup>Cs
    - b) 16% for <sup>60</sup>Co
    - c) 32% for <sup>90</sup>Sr-<sup>90</sup>Y
    - d) 15% for <sup>99</sup>Tc
    - e) 6% for <sup>14</sup>C
  - 2) Typically, a conservative beta efficiency of 10% is assigned for these types of problems. Therefore, to convert the cpm reading to a dpm value, the meter reading is multiplied by ten. (dpm = cpm X 10)
  - 3) Efficiencies for alpha and photon radiation are not typically quoted because the probes are not calibrated for either type of radiation. However, gamma efficiencies are low, about 1-2%, because of the shallow detector depth. Alpha efficiencies are highly dependent on the particle energy and distance from the source, but can be as high as 20%.
- e. Specific limitations and characteristics
- 1) Generally, environmental conditions, such as humidity and temperature, do not affect the response of the detector because it is sealed at a pressure slightly less than atmospheric pressure.
  - 2) Use of the hand probe at proper frisking speeds and distances is extremely important to ensure accurate results. The probe should be used at a distance of no more than 1/2" and at a speed of about 1" per second.

The numbers vary with probe

- 3) The mica window is extremely fragile and sufficient care must be taken to prevent any punctures which will ruin the detector.
  - 4) The detector probe is not calibrated for alpha radiation; however, it may be used for indication of alpha emission from contamination, if used properly.
2. Victoreen Model 489-4 Detector Probe (THYAC)
- a. The Model 489-4 detector probe is a cylindrical GM detector with a sliding beta shield and can be used for high count rate applications of contamination monitoring.
  - b. Detector
    - 1) The detector is a sealed Geiger-Mueller (GM) cylindrical detector.
    - 2) The shielded probe contains the cylindrical GM tube which has a stainless steel wall surrounding the entire detector volume.
    - 3) The fill gas in the GM tube is halogen-quenched argon.
    - 4) The operating voltage for the GM detector is  $900V \pm 50V$ .
  - c. Detector window and shielding
    - 1) The detector "window" is the  $30 \text{ mg/cm}^2$  stainless steel wall of the detector.
    - 2) Shielding provided by a 360E sliding steel shield.
  - d. The GM detector will detect any radiation that interacts within the sensitive volume of the detector.
    - 1) Charged particle radiation must pass through the detector wall before an interaction can take place; therefore, the minimum sensitivity for charged particle radiation is based on the wall thickness and distance from the detector.

- a) The minimum sensitivity for beta particles is about 200 keV with the shield retracted, which precludes the measurement of most average- energy, fission-product beta particles. The detector will not detect beta radiation with the shield in place.
  - b) Alpha particles can **not** be detected because all alpha particles would be stopped in the detector wall.
- 2) Photon radiation, such as gamma or x-ray, can interact in the detector walls and the fill gas to create a pulse. The minimum sensitivity for photon radiation is about 6 keV with the shield retracted and about 70 keV with the shield in place.
- e. Efficiencies for the detector are dependent on the type and energy of the radiation but are not typically quoted because the instrument ranges are adjusted to read the irradiation field value for the gamma-emitting isotope used during calibration.
  - f. Specific limitations and characteristics
    - 1) Generally, environmental conditions, such as humidity and temperature, do not affect the response of the detector because it is sealed at a pressure slightly less than atmospheric pressure.
    - 2) When used with a count rate meter, the meter reading (cpm) is converted to a dpm value by multiplying by thirty (dpm = cpm X 30).
    - 3) The detector probe is not calibrated and is not recommended for measurement of beta radiation due to the thickness of the detector wall.
3. Eberline Model AC-3 Alpha Hand Probe
- a. The Model AC-3 is an alpha scintillation detector used to identify alpha-emitting contamination.
  - b. Detector
    - 1) Scintillation detector using ZnS (Ag) powder embedded in tape.

Detector is not calibrated for beta radiation.



- 2) Active detector area is 9.1 inch<sup>2</sup> (59 cm<sup>2</sup>) within a 5 3/4 x 2 inch sampling area.
  - 3) Low gamma sensitivity.
- c. Detector window and shielding
- 1) Window is 1.5 mg/cm<sup>2</sup> aluminized plastic film.
  - 2) Total probe assembly is 11½ inches long x 2 3/4 inches wide x 3¼ inches.
  - 3) Clear plastic probe cover is supplied for protecting the detector window.
  - 4) Weight of probe is 1 pound 6 ounces.
- d. Efficiency
- 1) From a 1-inch diameter source or from 50 cm<sup>2</sup> of a large-area distributed Pu-239 source, 2 pi geometry.
    - a) Minimum efficiency is 28%.
    - b) Typical efficiency is 31%.
    - c) Sensitivity to Pu-239 source is typically 2 x 10<sup>7</sup> cpm per microcurie/cm<sup>2</sup>.
- e. Specific limitations and characteristics
- 1) Probe is sensitive to gamma radiation.
    - a) Not used in areas where gamma interference in mR/hr will indicate ≥300 cpm alpha.
    - b) The mr/hr value is affixed to each instrument during routine calibration.
  - 2) Detector window is very fragile. Puncture or damage to covering will cause detector to become sensitive to light. All detector windows must be checked for holes or damage.
  - 3) Erratic meter movement can be due to electrical short in probe connection cable. Check for damage by rotating probe in a circular motion. If erratic reading is noted, instrument is to be returned to calibration group.

Standard PM tube is replaced with less sensitive one

- 4) Detector is to be held 0.5 cm from the surface and moved at approximately 1-2 inches per second.

#### D. Count Rate Instruments

Objective 2.17.03

##### 1. Victoreen Model 496

- a. Victoreen Model 496 is an analog GM count rate meter.

- 1) Used in conjunction with GM probe assemblies to measure beta and gamma radiation.

- a) Victoreen 489-4

- b) Victoreen 110-C

- c) Eberline HP-210

Only detector with which meter is calibrated can be used.

- 2) Three operating ranges of 0-800, 0-8,000, and 0-80,000 cpm.

- 3) Response time of 10 seconds or less to 90% of the final reading.

- 4) Accuracy of  $\pm 10\%$  normally.

- 5) Weight of 4 pounds.

- b. Operation

- 1) Meter face readout of 0-800.

- 2) Rotary switch for power and range functions.

- a) off - setting for non-operation

- b) batt - initial selection for testing of battery strength, needle will identify battery strength.

- c) x1 - establishes meter reading times 1 as the activity in cpm (0-800 range).

- d) x10 - identifies meter reading times 10 as the activity in cpm (0-8,000 range).

- e) x100 - identifies meter reading times 100 as the activity in cpm (0-80,000 range).
  - 3) Volume control rotary switch
    - a) Audible indication of count rate by independently controlled speaker.
    - b) Functions of off and on to control speaker.
  - 4) Correction factors for beta/gamma cpm to dpm reading based on type of detector attached.
    - a) Thyac 489-4 - meter reading x30.
    - b) Pancake probes - meter reading x10.
2. Ludlum Model 12
- a. The Model 12 is an analog count rate meter
  - b. Electronic circuitry has potential for use of proportional, scintillation, and GM detectors
  - c. Available in three different detector configurations. Detector characteristics discussed earlier.
    - 1) Eberline HP-210 detector -used for beta-gamma measurement.
    - 2) Victoreen 110C - used for beta-gamma measurement.
    - 3) Eberline AC-3-7 Probe - used for alpha measurement.
  - d. Operating ranges of 0-500, 0-5,000, 0-50,000, and 0-500,000 cpm.
  - e. Fast-Slow toggle switch provides for meter response time selection.
    - 1) Slow - response time of 22 seconds for 90% of final reading.
    - 2) Fast - response time of 4 seconds for 90% of final
  - f. Operation
    - 1) Meter face readout of 0-500.
- Only detector with which calibrated can be used.

- 2) Range multiplier selector switch is a six-position switch.
    - a) OFF
    - b) BAT
    - c) x 1,000
    - d) x 100
    - e) x 10
    - f) x 1
  - 3) Audio on-off switch for operation of count rate speaker.
  - 4) Fast-Slow toggle switch to establish response time of 4 seconds (fast) or 22 seconds (slow).
  - 5) RES button provides a rapid means to reset the meter to zero.
  - 6) HV Test Button displays the detector voltage on the meter when depressed.
  - 7) Operates on two standard "D" cell batteries or rechargeable cells.
  - 8) Weight of 3.0 pounds, less detector and batteries.
3. LUDLUM MODEL 3-6
- a. The Model 3-6 is an analog survey instrument
  - b. Electronic circuitry has potential for use of proportional, scintillation, and GM detectors.
  - c. Operating ranges of 0-500, 0-5,000, 0-50,000, and 0-500,000 cpm.
  - d. Fast-Slow toggle switch provides for meter response time selection.
    - 1) Fast - response time of 5 seconds for 90% of the final reading.
    - 2) Slow- response time of 25 seconds for 90% of the final reading.

- e. Operation
  - 1) Meter face readout of 0-5,000.
  - 2) Range multiplier selector switch is a six-position switch.
    - a) OFF
    - b) BAT
    - c) x 100
    - d) x 10
    - e) x 1
    - f) x 0.1
  - 3) Audio on-off switch for operation of count rate speaker.
  - 4) Fast-Slow toggle switch to establish response time of 5 seconds (fast) or 25 seconds (slow).
  - 5) RES button provides a rapid means to reset the meter to zero.
  - 6) Operates on two standard "D" cell batteries or rechargeable cells.
  - 7) Weight of 3.5 pounds, less detector.
- 4. Ludlum Model 177-2 Count Rate Meter
  - a. Placed at specific locations for personnel contamination monitoring
  - b. Electronic circuitry has potential for use of scintillation, and GM detectors.
  - c. Available in conjunction with alpha, beta-gamma, and alpha-beta-gamma detection probes.
  - d. Operating ranges of 0-500, 0-5,000, 0-50,000, and 0-500,000 cpm.
  - e. Fast-Slow toggle switch provides for meter response time selection.

1) Slow - response time of 22 seconds for 90% of final reading.

2) Fast - response time of 2.2 seconds for 90% of final reading.

f. Operation

1) Meter face readout of 0-500.

2) Range multiplier selector switch is a six-position switch.

a) OFF

b) x 1

c) x 10

d) x 100

e) x 1,000

3) Audible click per radiation incident volume control adjustment.

4) Operates on 115 V AC only and does not contain battery pack.

5) RES Button provide a rapid means to reset the meter to zero.

6) Alarm Set Selector Switch is 11 position switch used to select a predetermined alarm threshold (0.5 to 500) at 100 cpm over background. Audible alarm setting of 1,000 Hz preset.

7) Weight of 4.2 pounds, less detector.

E. Personnel Contamination Monitor PCM-1B

Objective 2.17.04

1. Eberline Personnel Contamination Monitor, Model PCM-1B is a microprocessor-based radiation detection system.

2. Performs quick indication of beta-gamma contamination, with option of alpha capabilities.

a. PCM-1B has fifteen (15) independent gas-flow proportional detectors.

- b. Control processing unit (CPU) includes an Intel 8085 microprocessor, memory, and input-output lines.
  - c. Performs two-part personnel whole body survey by performing a right side then left side personnel body survey.
3. Operation mode
- a. Monitor measure and stores background values for all detectors.
    - 1) Checks for high background alarm levels.
    - 2) Checks for low or high count failures.
    - 3) Checks for low gas pressure conditions.
  - b. Ultrasonic motion sensor detects movement of person toward monitor.
    - 1) Background check is suspended.
    - 2) Display reads - "STEP UP - INSERT RIGHT ARM"Red LED flashing light while counting.
  - c. Placement of arm in arm cavity initiates personnel monitoring routine.
    - 1) Display reads - "COUNTING RIGHT SIDE"
    - 2) Counting continues for duration of specific counting time.
      - a) If no alarm levels detected, unit beeps and displays clearance.
      - b) Display reads - "RIGHT SIDE OK -- INSERT LEFT ARM"
  - d. Placement of left arm in cavity initiates monitoring.
    - 1) Display reads - "COUNTING LEFT SIDE"
    - 2) Counting continues for duration of specific counting time.
      - a) If no alarm levels detected, unit beeps and displays clearance.

- b) Display reads - "COUNT COMPLETE, YOU MAY PASS"
- c) Display accompanied by chime and the LED extinguishes.

#### 4. Alarm modes

##### a. Premature arm withdrawal.

Arm withdrawn prior to preset count time completion.

- 1) Alarm alert sounds.
- 2) Display read - "COUNT INCOMPLETE \*\*RECOUNT\*\*"
- 3) Reinsertion of arm restarts count.

Explain dead zones and sum zone readouts that may identify these.

##### b. Contamination detection

Activity in excess of alarm levels detected in either right or left side count.

- 1) Alarm alert sounds at end of count time.
- 2) Appropriate display appears - "ALARM: ZONE 1 - ZONE 2 - ZONE 3," etc.
- 3) Alarm and display continue for specified alarm hold time.
- 4) Alarm stops and display read - "CONTAMINATED -- PLEASE STEP OUT."

#### 5. Trouble Shooting

##### a. PCM-1B message display will illuminate the trouble or diagnostic lights to identify various monitor malfunctions. Description of basic malfunction conditions listed below.

##### b. High background - Background count rate in any zone(s) has increased above selected limit.

- 1) Alarm light, high background light, Sonalert, and "Channel Designation (i.e. 'Zone 1'): High Background" message are activated.

Sonalert - audible alarm.



- |  |   |
|--|---|
| <p>2) Area should be checked for radioactive sources and/or detector checked for dirt, moisture or radioactive contamination.</p>  | <p>Detector can be vacuumed for cleaning.</p>                                       |
| <p>c. High count fail –</p> <p>1) Alarm light, trouble light, Sonalert, and channel designation message are activated.</p> <p>2) Count capacity in any zone has been exceeded and PM Group to be contacted for troubleshooting.</p>  | <p>64k count capacity has been exceeded, likely by electronic surge.</p>            |
| <p>d. Low count fail or low sensitivity fail</p> <p>1) Alarm light, trouble light, Sonalert, and channel designation message are activated.</p> <p>2) May be result of component failure or decrease/loss of decrease/loss of counting gas. Detector identified should be checked for leak in mylar.</p> <p>3) Leak in mylar can be sealed with scotch tape.</p>   | <p>Detectors in train need to be checked.</p>                                       |
| <p>e. Contaminated detector -</p> <p>1) Contaminated detector light is activated along with contaminated detector message. Operation will continue with detector light on.</p> <p>2) Detector to be checked for contamination and decon around detector performed with masslin cloth. Detector area can be vacuumed.</p>   | <p>Note: Monitor should not be used until contamination light has been cleared.</p> |
| <p>f. Loss of gas pressure -</p> <p>1) Two cylinders used but cylinder No. 1 used until empty. When empty, "Bottle No. 1 Empty" light activated and No. 2 put in use automatically.</p> <p>2) If both cylinders fail (empty) the trouble light, "Bottle No. 2 Empty," and display with indicate "Failure**Out of Gas" message will be activated. Total loss of gas, PCM should be turned off and upon gas replacement a 4 hour purge before re-energizing of unit.</p> |   |
| <p>6. PCM-1B must not be used to monitor personnel with any</p>  |   |

trouble light illuminated. Monitor placed in "out of Service" mode until cause corrected.

F. Eberline PM-6

1. Microprocessor-based radiation monitor using gas-flow proportional detectors for whole body contamination scans.
2. Two basic types of PM-6s are typically used
  - a. PM-6A
    - 1) Uses eleven gas-flow counters to detect beta-gamma contamination.
    - 2) Same basic operating characteristics as PCM-1B.
    - 3) Source checked daily using beta-gamma source.
  - b. PM-6A-2
    - 1) Uses fifteen gas-flow counters to detect alpha or beta-gamma contamination.
    - 2) Four additional detectors used in hand pods to increase ability to detect hand contamination.
    - 3) Hand and foot detectors sensitive to alpha as well as beta-gamma contamination.
    - 4) Source checked daily using alpha and beta-gamma sources for both hand and foot detectors. Beta-gamma source is used on body detectors.
3. Source checks and troubleshooting PM-6 is same as PCM-1B.

G. Specialty Contamination Monitors - (*tool, bag, laundry monitors*)

Objective 2.17.05

NOTE: Site must add materials based on other contamination monitors used at the site. Text added must cover, at a minimum, the material required by the objective.

1. Detector type
2. Detector shielding and window
3. Types of radiation detected/measured

4. Energy response for measured radiation
5. Specific limitations/characteristics

### **III. SUMMARY**

#### A. Review major topics

1. General discussion/instrument selection
2. Count rate meter probes
3. Count rate meters
4. Personnel contamination monitors
5. Specialty contamination monitors

#### B. Review learning objectives

### **IV. EVALUATION:**

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.

**Course Title:** Radiological Control Technician  
**Module Title:** Air Sampling Equipment  
**Module Number:** 2.18

**Objectives:**

- 2.18.01 Identify the factors that affect the operator's selection of a portable air sampler.
- 2.18.02 Identify the physical and operating characteristics and the limitation(s) of the Staplex and Radeco portable air samplers.
- 2.18.03 Identify the physical and operating characteristics and the limitation(s) of Motor air pumps.
- 2.18.04 List the steps for a preoperational checkout of a portable air sampler.
- 2.18.05 Identify the physical and operational characteristics and the limitation(s) of beta-gamma constant air monitors (CAM's).
- 2.18.06 Identify the physical and operating characteristics and the limitation(s) of alpha constant air monitors (CAM's).

**References:**

1. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5<sup>th</sup> ed.; Pacific Radiation Corporation; 2008.
2. Operational Health Physics, Harold J. Moe.
3. ANSI N323A.
4. (Various Manufacturers Technical Manuals).

**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

Before the proper internal exposure control methods can be determined for personnel, an estimate of the airborne radioactivity concentration must be obtained. Airborne radioactivity measurements are necessary to ensure that the control measures are effective and continue to be effective. This lesson contains information about widely used air sampling equipment.

## C. Overview of Lesson

1. Selection of portable air samplers
2. Physical and operating characteristics and limitations
3. Preoperational checkout of portable air samplers
4. Beta-gamma constant air monitors

O.H.: Objectives

## D. Introduce objectives

**II. MODULE OUTLINE**

NOTE: The text is provided for some commonly used instruments. The site must adjust text as necessary for instruments used at each site. Text added for specific instruments used at the site must, at a minimum, cover material required by the objectives.

## A. Factors Affecting the Selection of Portable Air Samplers

Objective 2.18.01

1. Type of radiation emitted by airborne contaminant in question
2. Physical state of airborne contaminant
3. Type and duration of job being performed

Objective 2.18.02

**B. Physical and Operating Characteristics and Limitations****1. Staplex****a. Operational characteristics**

1) Centrifugal force is the method used to induce air movement

a) Centrifugal force produces kinetic energy

b) Resultant velocity pressure converted to suction for moving sampled air

2) Self-cooling

a) Inappropriate for long-term continuous sampling

3) Variable orifice flowmeter calibrated 0-70 cfm

a) Flow rate sticker on side is specific for appropriate collection method

b) Typical flow rate(s): 7-28 cfm

**b. Physical characteristics**

1) 110-V fan motor with on-off switch

a) Requires external power source

2) 4-inch filter holder assembly with intake screen

a) MSA charcoal adaptor available

3) Portable: 10 pounds

**c. Limitations**

1) Inappropriate for long-term continuous sampling

2) May create an airborne area due to exhaust

3) Potential "crawler" while in operation due to the high torque generated by the fan

4) DO NOT use in explosive atmospheres

**d. Methods of sampling**

- 1) Filtration
- 2) Absorption, if charcoal is used
- 3) Impaction, if impactor head is installed
- e. Placement for surveys
  - 1) Avoid creating airborne activity through stirring up dust with sampler exhaust air
  - 2) Tripods available
  - 3) May be hung on chain for optimum positioning
- f. Annular Kinetic Impactor Head
  - 1) Inertial Collector-Head collects large airborne particles such as plutonium without collecting coexisting particles containing radon and thoron
  - 2) Principle: Air to be sampled enters annular space at rear, makes a 180-degree turn at greased planchet, and out the center tube
  - 3) Operational characteristics
    - a) Size of particles collected can be varied by adjusting slit width and air flow velocity
  - 4) Physical characteristics.
    - a) Head replaces Staplex screened intake orifice
    - b) Lightly greased planchet placed on head intake
2. Radeco (H809-VI)
  - a. Operational characteristics
    - 1) Equipped with rotameter air flow indicator
      - a) Rotameter consists of
        - (1) A "float" which is free to move up and down
        - (2) A vertical tapered tube, which is larger at top than bottom and contains the float
      - b) Operates using air pressure

Objective 2.18.02

- (1) Air flows up the tube
  - (2) Causes float to rise
  - (3) Height to which float rises is proportional to air flow rate
- c) Many different types of floats
  - d) Rotameters are conventionally read at the highest point of maximum diameter, unless otherwise indicated
  - e) If in doubt about how to read a particular rotameter, check with supervision or Works Engineering Mechanic
- 2) Flow rate adjustable from 1 to 8 cfm
  - 3) 110-125 VAC
- b. Physical characteristics
- 1) Equipped with a two-stage turbine blower and one horsepower self-cooling universal type motor
  - 2) Sample head uses 2 in. or 47 mm particulate and iodine filters
  - 3) Instrument panel
    - a) Three-position switch - HIGH/OFF/VARIABLE
    - b) Control knob for FLOW ADJUST
    - c) Fuse holder
    - d) Rotameter
  - 4) Weight: 10 lbs
- c. Limitations
- 1) Cannot be used in explosive atmospheres
  - 2) Inappropriate for long-term continuous sampling



- d. Methods of sampling employed
  - 1) Filtration
  - 2) Adsorption, if charcoal is used

### C. Motor Air Pumps

Objective 2.18.03

- 1. Types of motor air pumps.
  - a. MotoAir
  - b. ITT
  - c. Eberline
- 2. These units normally used to sample for extended periods of time at low flow rates
- 3. Operational characteristics of typical motor air pumps.
  - a. Flow rate maintained relatively constant by regulator
  - b. Requires 110 V power supply
- 4. Physical characteristics of typical motor air pumps
  - a. Sample heads used designed to accept 2 in. diameter (47 mm) media for both particulates and iodine
  - b. Common components
    - 1) Carbon vane pump
    - 2) Constant flow air regulator
    - 3) Flow meter
  - c. Grounded three wire power cord is provided
- 5. Typical features - Eberline RAS-1
  - a. Operational characteristics.
    - 1) Rotameter type flow meter
    - 2) Flow rate range 0.5 to 3.5 cfm

- 3) Power requirement 5 amps
  - b. Physical characteristics
    - 1) "Screw in" type particulate filter holder
    - 2) "Clamshell" type iodine filter holder
    - 3) ON/OFF power switch
    - 4) Weight: 30 pounds
  6. Sampling considerations
    - a. Filter paper must cover intake screen
    - b. Charcoal cartridge holder must have good seal
    - c. Check flow rate after turning on and before turning off
  7. Reading a rotameter
    - a. Rotameter consists of
      - 1) A "float" which is free to move up and down
      - 2) A vertical tapered tube, which is larger at top than bottom and contains the float
    - b. It operates using air pressure
      - 1) Air flows up the tube
      - 2) Causes float to rise
      - 3) Height to which float rises is proportional to air flow rate
    - c. Rotameters are conventionally read at the highest point of maximum diameter, unless otherwise indicated.
- D. Preoperational Checkout of Portable Air Samplers
1. Current Calibration Sticker
  2. Physical Damage
    - a. Power cord in good condition

Objective 2.18.04

- b. All gaskets in place
  - c. General physical condition
    - 1) Housing
    - 2) Controls
  - 3. Working Condition
    - a. Operates properly
      - 1) Sound - no unusual noises
      - 2) Sight - no smoke, no excessive sparking from motor brushes
      - 3) Smell - no burning
      - 4) Feel - no unusual vibration, not overly hot to touch
    - b. Appropriate air flow
    - c. Controls on sampler are operable
    - d. Ensure filters and cartridges are loaded in proper orientation to air flow prior to sampling
- E. Beta-gamma Constant Air Monitors (CAM's)
- 1. General Characteristics
    - a. Function
      - 1) Continuously monitor quality of particulate beta-gamma airborne activity in selected area
    - b. Physical characteristics
      - 1) GM detector(s) - usually pancake type
        - a) Some utilize one GM detector to measure activity on filter
        - b) Other utilize two GM detectors
          - One GM detector to measure activity on filter

Objective 2.18.05

- Other GM detector to measure ambient background for background subtraction
- 2) Filter paper holder assembly in lead shield
  - 3) Strip chart recorder
  - 4) Mounted on enclosed, portable cart
  - 5) Photohelic air flow meter
  - 6) Alarm lights
    - a) High Activity alarm
    - b) Low air flow alarm
- c. Limitations of CAM's
- 1) Low air flow
    - a) Must be placed near or downwind suspected source
  - 2) Poor response to low energy beta
  - 3) Lead shield ineffective for high gamma energies
    - a) CAM must be in low background
  - 4) Responds to radon, thoron, and daughters
    - a) Produces fluctuating background on recorder
  - 5) Not very portable
    - a) Approximate weight 500 pounds
- d. Method of sampling - filtration
- e. Operation and use
- 1) Initial startup
    - a) Check all switches in off position
      - Master switch

- HV switch
- b) Plug in power cord (110 V)
  - Air blower will start
  - Reset any alarms that activate
- c) Ensure sufficient filter paper
- d) Turn master switch on and allow two minute warmup
- e) Turn HV switch on and allow 30 second warmup
- f) E & I to adjust the following settings
  - HV level
  - High and low level alarm settings
  - Scale switch overlap setting
- g) Set recorder speed selector switch
  - 3/4 in. per minute to ascertain chart moves
  - 3/4 in. per hour, routine operation
- h) CAM operating if slow buildup noted on recorder chart

#### F. Alpha Constant Air Monitors (CAM'S)

Objective 2.18.06

Continuously monitor quality of particulate alpha airborne activity in selected areas

1. Operating characteristics
  - a. Air pumping system pulls air through impactor head
  - b. Count rate meter monitors planchet which will activate high activity alarm horn and light at preset points
2. Physical characteristics
  - a. External cabinet features
    - 1) Power Supply

- 2) Magnehelic gauge
- 3) Count rate meter (CRM)
- 4) Recorder chart
- 5) Power switches
- 6) Outlets
- 7) Photohelic air flow meter
- 8) Alarm lights
  - a) Radiation alarm
  - b) Low flow alarm
- b. Internal cabinet features
  - 1) Annular Kinetic Impactor sample head
  - 2) Blower
  - 3) Planchet (greased with ZnS and Silicone)
  - 4) Photomultiplier (PM)
3. Limitation(s)
  - a. Does not give extremely accurate quantitative alpha measurement
    - 1) Gives warning of increase activity
    - 2) Possible to make estimates
  - b. Dust buildup and radon-thoron activity affect efficiency
4. Method of sampling - Impaction
5. Operation and Use
  - a. Initial startup
    - 1) Place new "Alpha Tak" planchet on impactor head
      - a) Open light tight box door

- b) Move PM tube housing from impactor head
  - c) Remove any used planchet
  - d) Place new planchet on impactor head
  - e) Move PM tube housing back into position
  - f) Close door
  - g) Indicate action on recorder chart.(date, time, etc.)
  - h) Take any used planchets to RC office for processing
- 2) Plug in power cord ensuring all switches are off prior to plugging power cord in
  - 3) Turn on switches in following order
    - a) Outlet switch
    - b) CRM power switch
  - 4) Set CRM to x 1 scale
  - 5) Set alarm to desired level
  - 6) Set CRM PHA/GROSS switch to GROSS
  - 7) Notify instrumentation group (e.g., I&C) and/or supervisor of any malfunctions

### III. SUMMARY

#### A. Review major topics

1. Selection of portable air samplers
2. Physical and operating characteristics and limitations
3. Preoperational checkout of portable air samplers
4. Beta-gamma constant air monitors

#### B. Review learning objectives

**IV. EVALUATION**

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.



**Course Title: Radiological Control Technician****Module Title: Counting Room Equipment****Module Number: 2.19****Objectives:**

- 2.19.01 Describe the following features and specifications for commonly used laboratory counter or scalers:
  - a. Detector type
  - b. Detector shielding
  - c. Detector window
  - d. Types of radiation detected and measured
  - e. Operator-adjustable controls
  - f. Source check
  - g. Procedure for sample counting
  
- 2.19.02 Describe the following features and specifications for low-background automatic counting systems:
  - a. Detector type
  - b. Detector shielding
  - c. Detector window
  - d. Types of radiation detected and measured
  - e. Operator-adjustable controls
  - d. Source check
  - e. Procedures for sample counting
  
- 2.19.03 Describe the following features and specifications for commonly used gamma/alpha spectroscopy systems used at your facility:
  - a. Detector type
  - b. Detector shielding
  - c. Detector window
  - d. Types of radiation measured
  - d. Procedures

**References:**

1. Radiation Detection and Measurement, Glenn F. Knoll.
2. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5<sup>th</sup> ed.; Pacific Radiation Corporation; 2008.
3. Operational Health Physics, Harold J. Moe.
4. ANSI N323A.
5. (Various Manufacturers Technical Manuals).

**Instructional Aids:**

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

**I. MODULE INTRODUCTION**

## A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

## B. Motivation

In this lesson, we will cover counting room equipment in relation to types used, purpose for, radiation monitored, operational requirements, and specific limitations and characteristics. The RCT uses information from these counting instruments to identify and assess the hazards presented by contamination and airborne radioactivity and establish protective requirements for work performed in radiological areas.

## C. Overview of Lesson

1. General principles
2. Laboratory counters or scalars
3. Low-background automatic systems
4. Gamma Spectroscopy

## D. Introduce objectives

O.H.: Objectives

**II. MODULE OUTLINE**

## A. Introduction

1. An overview of counters, scalars and associated equipment will describe the basic functions of counting equipment used to detect radiation activity.
2. The RCT uses information from these counting instruments to:
  - a. identify and assess the hazards presented by contamination and airborne radioactivity and;

- b. establish protective requirements for work performed in radiological areas.
3. Stand-alone counters or scalers measure gross activity while spectroscopy systems perform spectrum analysis to identify and quantify activity from specific nuclides.
4. The common uses of counting room equipment in various facilities will be discussed.
5. A variety of counting equipment is used, both manual and automated.
  - a. Shielded equipment to measure radioactivity just above background levels.
  - b. Equipment to measure gross counts of alpha, beta and gamma to determine if surface contamination limits are met.
  - c. Equipment to measure the energy spectrum for alpha and gamma radiation so that individual isotopes can be identified and quantified (e.g. to determine if an alpha emitter is a plutonium isotope, a uranium isotope or a radon daughter).
6. The counting systems use various types of detectors, including:
  - a. gas proportional counters for alpha and beta radiation;
  - b. sodium iodide, scintillation detectors for gamma spectroscopy;
  - c. zinc sulfide (ZnS) scintillation detectors for alpha radiation;
  - d. liquid scintillation for tritium and carbon 14;
  - e. surface barrier (semiconductor) detectors for alpha spectroscopy,
  - f. lithium drifted germanium (GeLi semiconductor) detectors for gamma spectroscopy,
  - g. high purity, germanium (HPGe semiconductor) detectors for gamma spectroscopy.

7. The most common uses of the equipment are to count:
  - a. Smears and swipes
  - b. Air filters
8. Nose swipes are also counted as one way to test if an individual has been exposed to airborne radioactive contamination.
9. Both workplace and stack emission air filters are counted to measure the concentration of specific radionuclides (e.g. plutonium, and uranium) and classes of radionuclides (e.g. mixed fission products).

## B. General Principles

A variety of counting room systems are used. The principles of these systems will be discussed in general and then specific systems will be described.

1. Detector Type
  - a. When looking for low levels of radioactivity from alpha emitters (e.g. U, Pu, etc.) it is important to minimize the background count rate from betas and gammas.
  - b. The principle used to accomplish this is pulse height discrimination.
  - c. Betas have a range that is about 100 times greater than alphas, so alphas will deposit about 100 times as much energy in a thin detector, producing a larger pulse than betas. Therefore alpha detectors are thin (typically  $1 \text{ mg/cm}^2$ ) and use pulse height discrimination to distinguish alphas from betas.
  - d. Alpha detectors are generally either gas proportional counters, ZnS scintillators, or silicon semiconductors.
  - e. Gamma spectroscopy requires good resolution to distinguish the different energy peaks. GeLi or HPGe semiconductors give the best resolution, though NaI scintillators are also used.
2. Detector Shielding
  - a. To reduce the background, shielding is often used.

- b. Betas can be shielded with aluminum or plastic.
  - c. Typical gamma shielding is a few inches of lead.
3. Detector Window
- a. Since alphas have a short range the windows are thin, typically 1 mg/cm<sup>2</sup> (or 0.25 mil plastic).
  - b. Some detectors have no window between the sample and the detector; in this case there is a gas purge system for gas proportional counters, or a light tight housing for scintillators.
  - c. The alpha range is so short that self-shielding is often significant, e.g. an alpha emitter buried in a filter may be shielded from the detector by the fibers.
4. Types of Radiation
- a. Some of the detectors discussed in objectives 1 and 2 are designed for alphas, some for betas, and some will count both.
  - b. Gamma spectroscopy is discussed in objective 3.
  - c. Most nuclides emit more than one type of radiation, but beware of exceptions (like Be-7 or C-14).
  - d. Beta background is greater than alpha, so alpha detectors use pulse-height discrimination to differentiate between alphas and betas.
  - e. Some gammas will generally be detected in these detectors, but thin detectors have low gamma efficiency, and lead shielding helps to reduce the gamma background still further.
5. Operator Adjustable Controls
- a. Counting room systems have a timer to allow the operator to measure the number of counts per minute (cpm).
  - b. The most common count time is 1 minute, but the count time can be selected by the operator.

6. Sources
  - a. National Institute of Standards and Technology (NIST) standard sources are used to check the systems.
  - b. Common sources are:
    - 1) Pu-239 for alpha
    - 2) Sr-90 for beta
7. Procedures
  - a. Procedures generally include:
    - 1) background count
    - 2) source check
    - 3) sample count
    - 4) background subtraction
    - 5) divide by time to get cpm
    - 6) correct for 4 pi efficiency to get dpm
    - 7) record the data

Objective 2.19.01

## B. Laboratory Counters or Scalers

In this section, specific laboratory counters or scaler systems are discussed, illustrating the general principles discussed above.

1. Sample Holder SH-4 with HP210 and ESP
  - a. The simplest system for counting smears is the portable contamination survey instrument, the Eberline smart portable ESP with hand probe HP210. ESP means Eberline Smart Portable. HP means Hand Probe.
  - b. Recall from lesson 2.17 that the HP-210 probe is a pancake GM detector with a thin (1.4 to 2 mg/cm<sup>2</sup>) window, suitable for detecting beta contamination, and alphas above 3 MeV. Window is thicker than most alpha detectors, so probe must be < 1/4 inch from source of alphas.

- |  |  |
|--|--|
| <ul style="list-style-type: none"> <li>1) The HP210T is shielded with tungsten to reduce gamma background.</li> <li>2) The HP210AL is shielded with aluminum to reduce beta background.</li> </ul> | <ul style="list-style-type: none"> <li>Shield gammas with high Z material.</li> <li>Shield betas with low Z material.</li> </ul> |
|--|--|
- c. The problem with using the HP210 for quantitative measurements (e.g. to satisfy release criteria) is one of ensuring a precise geometry.
  - d. The SH-4 sample holder solves this problem by holding the sample in a fixed position directly under the HP210 detector.
2. Eberline Scintillation Alpha Counter SAC-4
- a. The Eberline SAC-4 is a scintillation alpha counter. S.A.C. is an acronym
    - 1) The scintillation phosphor is ZnS powder on a plastic light pipe.
    - 2) The system is a self contained unit with the detector and associated electronics housed in a single unshielded box.
    - 3) The detector and sample are both in a light tight can, so no window is required between the ZnS detector and the sample.
  - b. The system will accept samples up to 2 inches in diameter by 3/8 inches thick. (Self shielding would be a major problem with samples this thick.)
    - 1) The sample holder in the slide drawer is adjustable. It can be moved closer to the detector for thin samples.
    - 2) The SAC-4 is calibrated with the sample holder in a certain position, so if the sample holder is moved, the calibration is no longer valid.
  - c. The electronic package consists of the high voltage power supply used to power the photomultiplier tube and determine its amplification, and a linear amplifier. Amplifier output is 0 to 10 V
    - 1) Only pulses with amplitudes above the discriminator level will be counted. Discriminator level is 1.25 V

See lesson 2.03

- 2) This will discriminate against betas because they will produce smaller pulses.
  - d. The output from the discriminator is counted by a six decade light emitting diode (LED) readout.
    - 1) The timing circuit is synchronized to the line frequency (60 Hz) and provides preset counting times from 0.1 to 50 minutes controlled by front panel switches.
    - 2) This scaler can also be operated in a manual mode which will continue to count until reset by the operator.
  - e. A Pu-239 source is used to check the system prior to each operating shift.
    - 1) Background counts are conducted as a part of the performance check and to check for detector contamination.
    - 2) The detector and sample drawer are easily removed for decontamination if required.
  - f. The gross count rate is obtained by dividing total counts by the time in minutes.
    - 1) Background counts (typically 0.3 cpm) are subtracted from gross counts to obtain net counts per minute (cpm).
    - 2) The net count rate (cpm) is corrected for efficiency to convert cpm to disintegrations per minute (dpm).
  - g. This counting system is used to obtain total activity and the procedures are followed as described in the SAC-4 manual. Each background, source count, and sample count is documented and kept on file.
3. NMC PC-5 and PC-55
- a. The PC-5 and PC-55 systems use gas flow proportional counters as the detectors.
    - 1) The gas used is P-10 (90% argon and 10% methane).

See lesson 2.03

Nuclear Measurement  
Corporation



- 2) The systems are self-contained units with the detector and associated electronics housed in the same box.
  - 3) The PC-55 is used to count both alpha and beta.
  - 4) The PC-5 may be manually adjusted to count either alpha or beta. It is normally set to count alpha only.
  - 5) The determination of an alpha count or a beta count is accomplished by pulse height discrimination.
- b. No external shielding is used.
- 1) Typical background for the unshielded detector is 2 cpm for alphas, and 60 to 100 cpm for betas.
- c. The PC-5 and PC-55 have identical detectors, 2.25 inch in diameter.
- 1) They may be installed with thin plastic windows with a thickness of 0.25 mil (0.00025 inch, 1 mg/cm<sup>2</sup>) or they may be installed with no window.
  - 2) If there is no window, the operator must purge with P-10 gas after inserting a sample and closing the gas tight door.
- d. Front panel controls allow for pre-set gas purge times of 12, 36 and 144 seconds.
- 1) If the detector is installed with a thin plastic window, the normal procedure is to flow the gas continually.
- e. The sample to be counted is placed in a 2 inch diameter planchet and placed in the sample drawer.
- 1) The sample drawer then slides the sample under the detector.
  - 2) Should the detector drawer or sample holder become contaminated during counting, it is a simple task to remove the detector and drawer for decontamination.
- f. The high voltage supply has a dual operating range of 300 - 1300 volts and 1300 - 2300 volts controlled from a front panel voltage potentiometer. RCTs do not normally adjust this.

Window is optional

- 1) The high voltage determines the optimum setting to discriminate alphas from betas.
- g. The count time is also set by front panel switches providing pre-set counting times in 0.1 minute increments up to 1000 minutes.
  - 1) In the automatic mode, the counter will count to the pre-set time interval.
  - 2) In the manual mode, the counter will continue to count until manually reset.
- h. Two sources are used to check the system for proper operation.
  - 1) The alpha source is Pu-239 electroplated on a nickel disc.
  - 2) The beta source is  $^{90}\text{Sr}/^{90}\text{Y}$  (Strontium-90 and its daughter, Yttrium-90).
  - 3) These sources are traceable to NIST (National Institute of Standards and Technology).

Objective 2.19.02

### C. Low-background Automatic Systems

1. In this section, several automatic counting systems are discussed.
  - a. The principles are the same as in section 1 (objective 1).
  - b. The essential differences between the systems in sections 1 and 2 are:
    - 1) Complexity of electronics
    - 2) number of detectors or automated sample changing
    - 3) shielding to reduce background
2. Canberra 2400
  - a. The Canberra 2400 is a low background automatic counting system.
    - 1) The primary detector is a gas flow proportional counter with a 2.25 inch diameter thin window, used

- to count both alpha and beta activity. Proportional counters use pulse height discrimination.
- 2) A second larger proportional counter, the guard detector, is used to count background.
  - 3) The gas used is P-10 (90% argon and 10% methane).
  - 4) The system may also incorporate a NaI scintillation detector, an option with the Canberra 2400 systems, to simultaneously count gamma rays.
- b. The sample detectors are surrounded by 4 inches of lead shielding to reduce background.
- 1) Typical background is 0.1 to 1 cpm alpha, 1 to 5 cpm beta, and 100 to 400 cpm gamma.
- c. Canberra 2400 systems are used principally to count smears and filters.
- 1) Gross counts for each sample are processed in the computer and converted to dpm.
  - 2) Smear counts above preset limits are highlighted and printed on a separate report.
- d. Performance checks are performed daily or prior to system use. NIST traceable sources of:
- 1) Pu-239 (Plutonium),
  - 2) Sr-90 (Strontium), and
  - 3) Tc-99 (Technetium) are used.
- e. The system has an automatic sample changer with a dual stack that can handle up to 100 samples.
- 1) One stack holds the samples to be counted and the other stack stores the samples that have been counted.
3. Berthold LB770
- a. The Berthold LB770 counting system is a low background semi-automatic counting system.
    - 1) The system uses eleven P-10 gas flow proportional detectors;

- 2) ten detectors are used to count 10 radioactive samples simultaneously,
  - 3) the other detector is used to count background radiation.
- b. Each detector has a 2.25 inch diameter by 0.25 mil (0.00025 inch) mylar window.
- 1) The detector bay is shielded with 4 inches of epoxy coated lead.
  - 2) Typical backgrounds are 0.1 cpm alpha and 1 or 2 cpm beta.
  - 3) Typical counting efficiencies are 27% alpha and 42% beta.
  - 4) The planchet is 0.25 inch deep, but a 0.25 inch thick sample would cause major self-shielding problems. Self shielding: see lesson 2.03.
- c. The Berthold systems are used primarily to count smears or filters.
- 1) Both alphas and betas are counted simultaneously in each detector.
  - 2) Determination of alpha or beta activity is accomplished by pulse height discrimination.
  - 3) The scalers in the Berthold systems are similar to those used in the PC-55 but with more sophisticated electronics that provide improved pulse shaping from the linear amplifier and better discrimination of both pulse amplitude and pulse shape.
- d. Plutonium-239 sources are used to check the system for alpha and  $^{90}\text{Sr}/^{90}\text{Y}$  sources are used to check for beta. Yttrium-90 is the daughter of Strontium-90.
- 1) These sources are traceable to NIST
- e. The Berthold system is controlled by a computer.
- 1) Both alpha and beta counts received from each sample are corrected for background and reported in one of three categories, to alert the operator.

- 2) If the count rate is below the minimum detectable activity (MDA, see lesson 2.03) it falls into category 1.
  - 3) A count rate that falls within predetermined limits, usually above MDA but below the limit for release to a controlled area (RadCon table 2.2) is category 2. MDA stands for Minimum Detectable Activity, see lesson 2.03.
  - 4) A count rate that is higher than the upper limit is category 3.
- f. Background and efficiency data are collected for each detector, stored and used for corrections.
- 1) Pre-set count times are determined by the operator and put into the computer.
  - 2) The count rate data from each detector is corrected and converted to dpm for output to the printer.
4. Liquid Scintillation Counters, LSC e.g. Packard 2550
- a. Tritium and C-14 emit such low energy betas that even a thin layer of air would stop the betas.
    - 1) To detect this radiation, the sample must be in intimate contact with the detection medium.
    - 2) This is achieved with a liquid scintillation system.
  - b. A liquid scintillation counting system uses a "cocktail" that immerses the sample in the counting medium to maximize the detection efficiency for low energy beta emitters.
    - 1) This cocktail includes a liquid scintillator to convert the energy deposited by low energy betas into light photons, which are then counted using photomultipliers.
  - c. The sample chamber, containing the sample vial and photomultiplier tubes, is light tight.
    - 1) Since stray electrons can be spontaneously emitted from the photocathode, or by the dynodes in the photomultiplier tube, two tubes are used with

coincidence circuitry to reduce this source of noise called "dark current".

- 2) Typical background for beta is 20 cpm.
- d. The LSC system is typically used to count tritium samples from swipes, water samples, and oil samples (vacuum pumps).
  - 1) Tritium is also collected by drawing air samples through silica-gel traps or glycol bubblers.
- e. To calibrate the system, a series of cocktails with known amounts of tritium are prepared.
  - 1) These sources are loaded into the first sample holder (a tray of 10 sample vials).
  - 2) The computer program calculates the detector efficiency for each calibration source.

Objective 2.19.03

#### D. Gamma Spectroscopy

1. The instruments discussed in objectives 1 and 2 are designed to detect alphas and/or betas, and make a gross count of total alpha and beta activity.
  - a. In order to identify specific radionuclides, the unique spectrum of energies particular to each radionuclide is used.
  - b. This technique is known as spectroscopy.
2. Alpha emitters (e.g. Th, U, Pu, Am and their daughters) have characteristic alpha energies, but alpha spectroscopy, detecting the alphas directly, is not optimal, because the energy loss of alpha particles between the sample and the detector smears the energy spectrum.
3. Gamma spectroscopy usually uses germanium detectors (GeLi or HPGe) because the good resolution obtained with these detectors enables gammas with nearly the same energy to be distinguished or resolved.
4. EG&G Ortec Gamma X
  - a. The Gamma X Spectroscopy system uses an HPGe coaxial photon detector to perform gamma and x-ray spectroscopy in the energy range from 3 keV to 10 MeV.

- b. Detector Type
  - 1) The detector is made of n-type high purity germanium semiconductor (HPGe).
  - 2) A 30 liter dewar of liquid nitrogen is used to cool the detector.
- c. Detector Shielding
  - 1) The detector is shielded by 4 inches of pre World War II steel.
  - 2) This steel is used when a low background is desired as it was manufactured before radioactive fallout from nuclear weapons appeared in trace quantities.
  - 3) A sample holder inside the shield allows the sample to be positioned at distances from less than 1 cm up to 40 cm from the detector end cap. Artificial radioactivity is discussed in Lesson 1.06.
- d. Detector Window
  - 1) The detector window is 0.5 mm thick beryllium.
- e. Types of Radiation Measured
  - 1) The gamma spectrometer is designed to detect gammas and x-rays from alpha emitting nuclides, and sort the data in a multi channel analyzer to produce a spectrum that is characteristic of the nuclide.
  - 2) The peaks in the spectrum are close together, so excellent resolution is required to distinguish the peaks.
  - 3) Typical resolution from a germanium semiconductor detector (HPGe or GeLi) is better than 1%, which means that if the photon energy is 100 keV, the width of the peak is less than 1 keV.
  - 4) Photons from two different nuclides that are 1 keV apart will be seen as two distinct peaks.
- f. Procedures

- 1) Energy and efficiency calibrations are obtained using two different sources that are NIST standards.
- 2) These are mixed sources that contain several gamma emitting nuclides.
- 3) One source contains isotopes of Americium (Am), Antimony (Sb), and Europium (Eu).
- 4) The second mixed source contains isotopes of Cadmium (Cd), Cerium (Ce), Cobalt (Co), Strontium (Sr), Tin (Sn), Cesium (Cs), and Yttrium (Y). These sources provide several calibration energies.
- 5) The energy and efficiency calibration values are then used by the analysis software.
- 6) Specific procedures are written to direct the operator through the sample and computer setup, and the computer analysis.
- 7) The original copy of the results is kept on file for 1 year and then archived for 75 years.

### III. SUMMARY

#### A. Review major points

1. General principles
2. Laboratory counters or scalers
3. Low-background automatic systems
4. Gamma Spectroscopy

#### B. Review learning objectives

### IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.