

Part 6 of 9

Radiological Control Technician Training
Site Academic Training Study Guide Phase I



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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.

INTRODUCTION

10 CFR 835 establishes radiation protection standards, limits, and program requirements for protecting individuals from ionizing radiation resulting from the conduct of DOE activities. It is important to maintain the proper documentation to ensure that these standards and requirements are being met. An RCT plays a vital role in supporting these requirements through proper documentation.

PURPOSE AND REQUIREMENTS

Radiological control records are needed to demonstrate the effectiveness of the overall Radiation Protection program at DOE facilities. The records are used to document radiological safety afforded to personnel on-site. Radiological control records become valuable tools in work planning, evaluating past trends, and guiding future performance goals. These records may become the basis for public disclosures, legal proceedings, medical assessment and audits to show compliance with company, state or federal requirements. Because of this, it is important that these records be of high quality, readily retrievable, and managed for the prescribed retention period. It is suggested that these records be cross-referenced, when applicable, to aid in their retrieval.

References:

1. 10 CFR Part 835 (2007) "Occupational Radiation Protection.
2. "U.S. Department of Energy Radiological Control Standard"(2008).

RADIOLOGICAL RECORDS MANAGEMENT PROGRAM

Each DOE site must have a radiological records management program to ensure that auditable records and reports are controlled through the stages of creation, distribution, use, arrangement, storage, retrieval, media conversion and disposition. The radiological records management program should include the following:

- a. Radiological Policy Statements
- b. Radiological Control Procedures
- c. Individual Radiological Doses
- d. Internal and External Dosimetry Policies and Procedures (including Bases Documents)
- e. Personnel Training (course records and individual records)
- f. ALARA Records
- g. Radiological Instrumentation Test, Repair and Calibration Records
- h. Radiological Surveys
- i. Area Monitoring Dosimetry Results
- j. Radiological Work Permits
- k. Radiological Performance Indicators and Assessments
- l. Radiological Safety Analysis and Evaluation Reports
- m. Quality Assurance Records
- n. Radiological Incident and Occurrence Reports (and Critique Reports, if applicable)
- o. Accountability records for sealed radioactive sources
- p. Records for release of material to Controlled Areas
- q. Reports of loss of radioactive material.

2.01.01 List the types of records/reports that the Radiological Control group is responsible for maintaining at your site.

(Insert site specific information here.)

RADIOLOGICAL RECORD KEEPING STANDARDS

Record keeping standards have been set by the Department of Energy. In addition to the requirement of being accurate and legible, all radiological records must include the following:

- identification of the facility, specific location, function, and process
- signature or other identifying code of the preparer and date
- legible entries in black ink
- corrections identified by a single line-out, initialed, and dated
- supervisory signature to indicate review and proper completion of the forms.

Each radiological control organization should maintain a file of names, signatures and initials for future identification of the person who signed or initialed a record. In addition, radiological control records should not include:

- records that are corrected using opaque substances
- records that contain shorthand or other nonstandardized terms.

TYPES OF RADIOLOGICAL RECORDS

Various types of records are included in the radiological records management program. These records fall into the following categories:

Employment History Records

Records detailing an employee's previous and on-going radiological work assignments, yearly doses at DOE and non-DOE facilities must be maintained. Where practical, the association between the radiation dose and job function must be preserved for trend analyses and future worker health studies.

Personnel Radiological Records

Occupational Radiation Dose Records must be maintained for all contractor, subcontractor, and Federal employees who are part of the personnel dosimetry program. These records include results of personnel extremity, skin, eye and whole body external dose measurements. The records also contain internal dose information, including in vivo measurements, urine, fecal and other specimen analysis and dose assessments. A complete record of radiological incidents and occurrences involving personnel dose must also be retained. The investigation and counseling of personnel radiological concerns must also be documented and maintained within the radiological control record management program.

Medical Records

Reports of periodic medical examinations and evaluations, respirator fit-testing results and records of medical treatment performed in support of the radiological control program should be maintained. Sites are encouraged to maintain nonoccupational radiation doses, such as therapeutic or large amounts of diagnostic radiation doses for employees.

Radiological Training and Qualification Records

Records of training and qualification in radiological control are permanently maintained to demonstrate that a person received appropriate information to perform the work assignment in a safe manner. Qualification standard records are retained for on-the-job, practical and formal classroom training. Training and qualification records are available to first-line supervision and management to aid in making work assignments. Included in the training records maintained, are quizzes, tests, responses and acknowledgements of training, with the date and signature of the person trained.

Instrumentation and Calibration Records

Records of calibration, modification or maintenance, and periodic operational checks of fixed, portable, and laboratory radiation measuring equipment must be maintained. These records include frequencies, method, dates, personnel, training and traceability of calibration sources. Records of additional tests and checks of instrumentation used in conjunction with a suspected overexposure, questionable indication, or unusual occurrence are also be retained.

Radiological Control Procedures

Sites should maintain radiological control procedures, policies, ALARA records, work procedures, Radiological Problem Reports, Radiation Work Permits, and supporting data as part of their radiological control record management program. Specific requirements for each of these documents can be found in the DOE RCS.

2.01.02 Describe the types of records and reports used at your facility 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:*

(Insert site specific information here.)

RECORDS MANAGEMENT

All records are required to be stored in a manner that ensures that they can be retrieved, in addition to being able to maintain their integrity and security. Once a record has been created, reviewed, and signed by appropriate supervision, the record should be considered complete and must not be modified. Subsequent errors identified in a completed record should be corrected by creating a supplemental record that includes traceability for the correction. Radiological Control records should be protected from temperature extremes, moisture, infestation, electromagnetic fields, excessive light, stacking, theft, and vandalism. Protective measures should include vaults, file rooms with fixed fire suppression, fire-rated cabinets, duplicate storage, or a combination of these.

2.01.03	<i>Explain the requirements for the records management system, such as QC, auditability/retrievability, management information at your facility.</i>
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(Insert site specific information here.)

RADIOLOGICAL REPORTING

All personnel that are monitored by a personnel dosimetry program shall be provided an annual report of their radiation exposure. A person may also receive a current radiation dose record upon special request. Terminating employees will be given an exposure report within 90 days of their last day of employment summarizing their radiation dose for the total period of employment at the reporting facility.

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.

References:

(Add any site-specific references.)

2.02.01 Explain the importance of good communication.c. Energy

IMPORTANCE OF COMMUNICATION

Good communication is important in everyday life to make sure our message is clear, understood, and received. A clear concise communication eliminates confusion and the possibility of misunderstanding. It is important that the receiver understand the communication without unnecessary interpretation or guess work. For a communication to be completed there must be a receiver. The receiver is the person or group that the communication is intended. For a good communication process there must be a clear concise message, a medium of transmission (i.e. telephone, telegraph, E-mail, letter, signal flag, etc.), and a receiver. If a response is required by the receiver, this can serve as confirmation of reception of the communication, however, a response alone does not indicate the communication was understood correctly. Misunderstanding of

communication can potentially cause personal as well as physical damage to equipment and surroundings.

In all communication processes, a sender of the communication must not assume knowledge that is needed for safe execution of the desired response. The communication must contain all pertinent information. Assuming or hoping the receiver has a given understanding of a process can lead to an unsafe condition. This is especially true in emergency situations that require immediate action or response. Make sure in all communications that desired responses are not outside the abilities or scope of the individual or group.

2.02.02 *Identify the two methods of communication and be able to determine different types of each.*

METHODS OF COMMUNICATION

In today's atmosphere of technology, there are methods of communications that seemed unlikely just 20 years ago. Who would have thought that a car phone would be as common as a home telephone. In general, communication can be broken into two groups, verbal and nonverbal.

Verbal methods of communication include talking directly to another person, telephone conversation, voice mail, video tele-conferencing, and various other available mediums. Verbal methods generally allow discussion of details followed by questions and/or an immediate response. Verbal communication allows flexibility in the message along with added information without too much difficulty in transmission.

Nonverbal methods of communication include signs, letters, signals, gestures, documents, E-mail, and various other available mediums. Nonverbal methods can limit the amount of information transmitted due to the difficulty in the transmission method.

2.02.03 *Describe different types of communication systems.*

COMMUNICATION SYSTEMS

There are several communication systems available at most DOE sites. These may include public address system, telephones, two-way radio, pagers, computer mail system, and computer based bulletin boards. Following is a brief generic description of each of these communication systems. The description is not meant to be all inclusive, but a cursory overview of key aspects of each system.

Public Address

The public address system consists of loud speakers and calling stations located throughout an area to provide audible notification to all personnel within the area. The public address system may be used for routine messages, contacting groups or individuals, items of interest to the general population, and emergency notifications or warnings. The public address system should be administratively controlled to ensure effectiveness in contacting facility personnel and availability during emergency conditions.

Telephones

Telephones provide a means for point to point communication. The telephone may be considered semiprivate when compared to the public address system, however while on a DOE facility, all calls are subject to monitoring for security reasons. The telephone system may offer the ability to leave a voice message whenever the receiving party is unavailable. The telephone system provides communication, but is subject to usage by other individuals which may impede your contacting the person or persons needed in an emergency situation.

Two-way Radio

Two-way radio communication provides a direct link to other individuals on your frequency or net. Although "traffic" on the radio may impair your message from being clearly understood, usage is controlled by possession of a radio with the correct frequency. Radio communication is subject to interference by outside sources, which may garble or mask the message. This may be of significance during emergency situations when location or type of emergency in progress must be relayed to response teams. Two-way radios do provide mobility and access while at remote locations.

Pagers

Pagers are small electronic devices capable of receiving signals from the telephone system to alert the carrier of intended communication from another party. Pagers provide access to personnel while away from the work location. Most pagers provide only a voice message or phone number to contact. Pagers normally do not allow the carrier to respond directly to the page verbally. Pagers provide a means of contacting personnel when their whereabouts are unknown, but are assumed to be within the site boundaries or very nearby.

Computer Mail Systems

Computer mail systems provide communication between computer terminals. Most systems are linked via a local area network. This link enables users to

contact individuals or groups directly and leave written messages for these individuals to receive. Computer mail systems enable the user to contact receivers directly while other users are unaware.

Computer Bulletin Boards

Computer bulletin boards provide communication to anyone with access to the bulletin board. The user provides messages or information without knowing who will receive the information. Usually messages and information of general subject matter or routine information that apply to most users are available on a bulletin board. Most bulletin boards are controlled with minimal requirements for access. Bulletin boards provide a means for communicating with a large diverse group.

2.02.04 *Describe the FCC and DOE guidelines regarding proper use of communication systems.*

FCC AND DOE RULES AND REGULATIONS

When using communication systems licensed by the Federal Communications Commission and operated by the Department of Energy, one cannot:

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

2.02.05 Describe general attributes of good communications.

GENERAL ATTRIBUTES OF GOOD COMMUNICATIONS

- Minimize the use of abbreviations and acronyms. Only abbreviations and acronyms from an approved list should be used in facility communication.
- Make all oral instructions clear and concise. Do not include multiple actions in a verbal instruction which may get confused or misunderstood.
- Ensure the identity of the person(s) is/are clearly understood. Identify yourself and your position, and ensure that you know to whom you are speaking.
- Use clear, precise terminology. Do not use slang terms. Avoid words that sound alike. Use commonly agreed upon terms. Employ the phonetic alphabet for clarification. (See Table 1)

Table 1. Phonetic Alphabet and Numbers

A - Alpha	J - Juliett	S - Sierra	1 - One
B - Bravo	K - Kilo	T - Tango	2 - Two
C - Charlie	L - Lima	U - Uniform	3 - Three
D - Delta	M - Mike	V - Victor	4 - Fower
E - Echo	N - November	W - Whiskey	5 - Fife
F - Foxtrot	O - Oscar	X - X-Ray	6 - Six
G - Golf	P - Papa	Y - Yankee	7 - Seven
H - Hotel	Q - Quebec	Z - Zulu	8 - Eight
I - India	R - Romeo	. - Point	9 - Niner
			0 - Zero

- Repeat back messages, either paraphrased or verbatim.
- Speak distinctly and deliberately.
- Acknowledge all communications.

2.02.06 *Explain the importance of knowing how to contact key personnel.*

CONTACT OF KEY PERSONNEL

The importance of knowing how to contact key personnel can not be understated. The importance lies in getting the knowledgeable people at the location they are needed. This can apply to emergency situations, routine circumstances, or nonroutine circumstances. The ability of the RCT to contact key personnel can reduce personnel injury, equipment damage, uncontrolled radioactive release, unrestricted movement of controlled materials, and other important actions. The RCT must be aware of the location of communication equipment, phone numbers or pager numbers, and/or emergency numbers regardless of location. Familiarity with the working environment will reduce the time needed to contact key personnel. The RCT must be aware of the location, situation, and personnel or equipment involved. This information must be relayed without misinterpretation to key personnel to afford proper response.

2.02.07 *Identify the communication systems available at your site and methods available to contact key personnel.*

SITE COMMUNICATION SYSTEMS

(Insert site specific information here.)

2.02.08 *Describe the emergency communication systems available at your site.*

SITE EMERGENCY COMMUNICATIONS

(Insert site specific information here.)

SUMMARY

This lesson has covered topics related to effective communications, contacting key personnel, and emergency communications. As an RCT you should be aware of your location and what communication systems are available to you while working on any job or situation.

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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.

INTRODUCTION

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 radiation protection personnel are using activity measurements to make decisions that may affect the health and safety of workers at those facilities and their surrounding environments.

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

References:

1. Chase & Rabinowitz, "Principles of Radioisotope Methodology," 3rd Edition, Burgess Publishing, 1987.
2. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5th 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.

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.

GENERAL SOURCES OF ERROR

Assuming the counting system is calibrated correctly, there are five general sources of error associated with **counting** a sample:

1. *Self-absorption*
2. *Backscatter*
3. *Resolving time*
4. *Geometry*
5. *Random disintegration* of radioactive atoms (statistical variations).

Self-Absorption

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

- Liquid samples with a high solid content
- Air samples from a high dust area
- Use of improper filter paper may introduce a type of self-absorption, especially in alpha counting (i.e., absorption by the media, or filter).

Personnel counting samples should ensure the correct sample media is used, and that the sample does not become too heavily loaded with sample material. Count room personnel should be routinely checking samples for improper media or heavily loaded samples.

Backscatter

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. 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). The amount of backscattered radiation increases as the energy of the radiation increases and as the atomic number of the backing material increases. 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. 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).

$$\text{(Equation 1)} \quad BF = \frac{\text{counts} - \text{with} - \text{reflector}}{\text{counts} - \text{without} - \text{reflector}}$$

Normally, backscatter error is accounted for in the efficiency or conversion factor of the instrument. However, if different reflector materials, such as aluminum and stainless steel, are used in calibration and operation, an additional unaccounted error is introduced. (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. Any deviation from that reflector material will introduce an unaccounted error and reduce confidence in the analysis results.

Resolving Time

Resolving time is the time interval which must elapse after a detector pulse is counted before another full-size pulse can be counted. 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. As the activity, or decay rate, of the sample increases, the amount of information lost during the resolving time of the detector is increased. As the losses from resolving time increase, an additional error in the measurement is introduced. Typical resolving time losses are shown in Table 1.

Count rate (cpm)	GM Tube ¹	Proportional ²	Scintillation ³
20,000	1.7%	< 1%	< 1%
40,000	3.3%	< 1%	< 1%
60,000	5.0%	< 1%	< 1%
100,000	8.3%	< 1%	1.0%
300,000	25.0%	< 1%	3.5%
500,000	42.0%	1.5%	5.8%

¹ GM tube: 50 μ s resolving time

² Proportional detector: 2 μ s resolving time

³ Scintillation detector: 7 μ s resolving time

Resolving time losses can be corrected by using the equation:

(Equation 2)
$$R = \frac{R_o}{1 - R_o \tau}$$

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

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.

Geometry

Geometry related counting errors result from the positioning of the sample in relation to the detector. Normally, only a fraction of the radiation emitted by a sample is emitted in the direction of the detector because the detector does not surround the sample. If the distance between the sample and the detector is varied, then the fraction of emitted radiation which hits the detector will change. This fraction will also change if the orientation of the sample under the detector (i.e., side-to-side) is varied.

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. This is especially critical for alpha counting, where any change in the sample-to-detector distance also increases (or decreases) the chance of attenuation of the alpha particles by the air between the sample and detector.

Common sources examples of geometry-related errors include:

- Piling smears and/or filters on top of each other in the same sample holder (moves the top sample closer to the detector and varies the calibration geometry).

- Using deeper or shallower sample holders than those used during calibration (changes the sample-to-detector distance).
- Adjusting movable bases in the counting equipment sliding drawer (changes the sample-to-detector distance).
- Using too many or inappropriate sample holders or planchets (changes the sample-to-detector distance). Sources not fixed in position can change can change geometry and reduce reproducibility.
- Plexiglass shelving in counting chamber is improperly set.

Random Disintegration

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

STATISTICS

Statistics is a branch of mathematics that deals with the organization, analysis, collection, and interpretation of statistical data. 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."

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.

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.

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). Luckily, we can define most observations in terms of two possible outcomes. For example, look at the following table:

Trial	Definition of Success	Probability of Success
Tossing a coin	"heads"	1/2
Rolling a die	"a six"	1/6
observing a given radioactive nucleus for a time, t	The nucleus decays during the observation	$1 - e^{-\lambda t}$

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.

Now, to study these processes, we can use proven, statistical models to evaluate our observations for error. Consider the possibilities when throwing two dice. There are 36 possible outcomes when throwing two dice, as indicated in Table 3.

Table 3. Possibilities in Rolling Dice

<u>Result</u>	<u>Possibilities</u>	<u>No. of Possibilities</u>
2	1&1	1
3	1&2,2&1	2
4	1&3,2&2,3&1	3
5	1&4,2&3,4&1,3&2	4
6	1&5,2&4,3&3,4&2,5&1	5
7	1&6,2&5,3&4,4&3,5&2,6&1	6
8	2&6,3&5,4&4,5&3,6&2	5
9	3&6,4&5,5&4,6&3	4
10	4&6,5&5,6&4	3
11	5&6,6&5	2
12	6&6	1

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.

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.

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 shown in Figure 1.

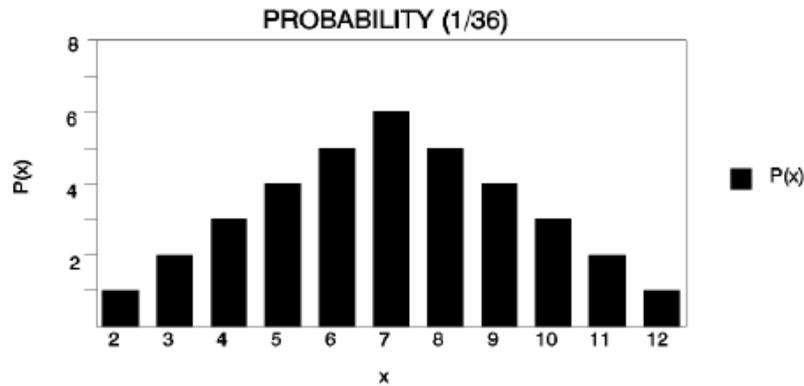


Figure 1. Probability in a Binary Process

The area under the curve can be mathematically determined and would correspond to the probability of success of a particular outcome. 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.

This is what statistics is all about; random *binomial* processes that should produce results in certain patterns that have been proven over the years. The three models that are used are distribution functions of binomial processes with different governing parameters. These functions and their restrictions are:

- **Binomial Distribution**

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

- **Poisson Distribution**

A simplified version of binomial distribution is the *Poisson* (pronounced "pwusówn") distribution, which is **valid when the probability of success, $P(x)$, is small**. 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. Thus, the curve would appear as seen in Figure 2.

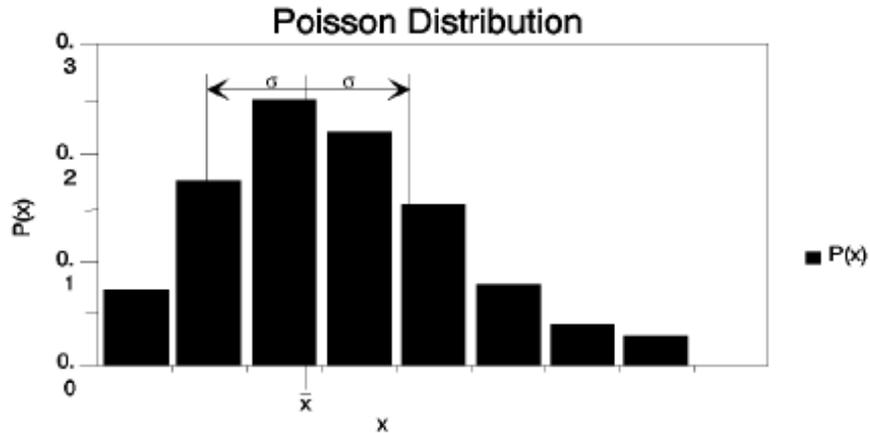


Figure 2. Predicted Successes for Poisson

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. This will be discussed in greater detail later.

- **Gaussian Distribution**

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**. A graph of a Gaussian distribution function is shown in Figure 3.

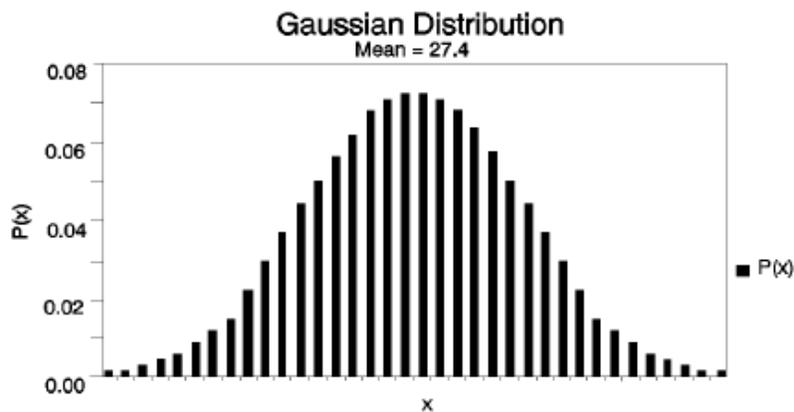


Figure 3. Predicted Successes for Gaussian

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. Also note that the mean, or average number of successes, is at the highest point, or at the center of the curve.

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

2.03.02 *State the two purposes for statistical analysis of count room operations.*

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:

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

2.03.03 *Define the following terms:*
 a. *mode*
 b. *median*
 c. *mean*

DEFINITIONS

Mode An individual data point that is repeated the most in a particular data set.

Median The center value in a data set arranged in ascending order.

Mean The average value of all the values in a data set.

2.03.04 *Given a series of data, calculate mode, median, or mean.*

<u>Student</u>	<u>Test Score</u>
Susan	80
Richard	82
Greg	86
Peter	88
Andrew	90
Wanda	92
Randy	95
Jennifer	95
Sarah	95

Figure 4. Sample Data Set

DETERMINATION OF MODE, MEDIAN, AND MEAN

- Determination of the Mode: In the set of test scores above, a score of 95 occurs (i.e., is repeated) more often than any other score.
- 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 in Figure 4 is 90.
- 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 nine test scores is 89.

Mean determination is often expressed using special symbols, as illustrated in the following equation:

(Equation 3)
$$\bar{x} = \frac{\sum x_i}{n}$$

where:

- \bar{x} = mean (sometimes pronounced "x bar")
- x_i = data point with index i
- n = number of data points
- Σ = summation symbol $\Rightarrow \sum_{i=1}^n x_i = x_1 + x_2 + x_3 + \dots + x_n$

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.

VARIANCE AND STANDARD DEVIATION

Using the Gaussian distribution model depicted in Figure 4 (below) 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.

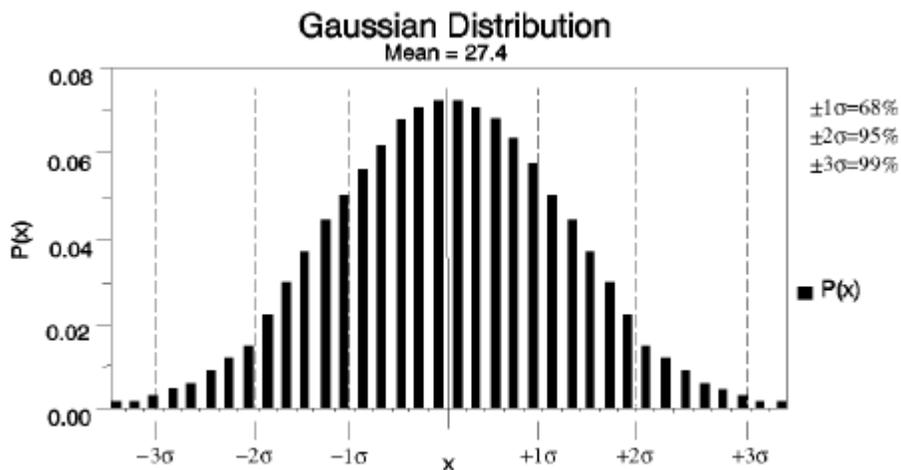


Figure 5. Gaussian Distribution with Standard Deviations

Variance

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

Standard Deviation

Mathematically, in the normal distribution, the standard deviation is **the square root of the variance**. A term more precise than the variance is *standard deviation*, represented by a σ (pronounced "sigma"). The standard deviation of a population is defined mathematically as:

(Equation 4)
$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n}}$$

where: σ = biased standard deviation of the population
 x_i = sample counts for each data point
 \bar{x} = mean
 n = number of data points

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. If data points are scattered, the curve will be lower and not as steep and have a larger numerical value for a standard deviation.

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 (1σ); 95.4% of the area under the curve falls between the data point located at \pm two standard deviations (2σ), etc. 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):

- 68.2% of the time the observed successes (or counts) will be within ± 1 standard deviation of the mean.
- 95.4% of the time the observed successes (or counts) will be within ± 2 standard deviations of the mean.
- 99.97% of the time the observed successes (or counts) will be within ± 3 standard deviations of the mean.

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.

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. In performing the calibration of the system, a radioactive source with a known activity is counted twenty times for one minute each time. Using the data from the twenty counts, the mean and standard deviation can be calculated. The mean can then be used to determine the efficiency of the system while allowing for a certain number of standard deviations during operation. The twenty counts can also be used to perform another required test of the system's performance, the chi-squared test (see below).

Example 2.03-1

Calculate the mean and sample standard deviation for the following data set: {151, 161, 143, 145, 121, 150, 135, 142, 135, 146}.

Using a table or spreadsheet we can arrange the data points and determine the required statistical values:

n	x	$(x - \bar{x})^2$
1	151	65.61
2	161	327.61
3	143	0.01
4	145	4.41
5	121	479.61
6	150	50.41
7	135	62.41
8	142	0.81
9	135	62.41
10	146	9.61

2.03.07 State the purpose of a Chi-squared test.

CHI-SQUARED TEST

The *Chi-squared test* (pronounced "ki") is used to determine the *precision* of a counting system. Precision is a measure of exactly how a result is determined without regard to its *accuracy*. 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.

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. This range represents the expected (or predicted) probability for the chosen distribution. 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. If the value is too high, it tells us that there is too much randomness in the observed data.

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? If it does NOT fit a curve indicating sufficient randomness, then the counting instrument may be malfunctioning.

The Chi-squared value is calculated as follows:

(Equation 5)
$$X^2 = \frac{\sum (x_i - \bar{x})^2}{\bar{x}}$$

Example 2.03-2

Using the data from Example 2.03-1, determine the Chi-squared value for the data set.

2.03.08 State the criteria for acceptable Chi-squared values at your site.

(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 counting system.

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

QUALITY CONTROL CHARTS

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. 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. QC charts, then, enable us to track the performance of the system while in use.

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.

When the system is calibrated and the initial calculations performed, the numerical values of the mean ± 1 , 2, and 3 standard deviations are also determined.

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.

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. 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.)

2.03.11	State the purpose of calculating warning and control limits.
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SYSTEM OPERATING LIMITS

The values corresponding to ± 2 and ± 3 standard deviations are called the upper and lower *warning* and *control limits*, respectively. The results of the daily source counts are graphed daily in many countrooms. Most of the time our results will lie between the lines corresponding to ± 1 standard deviation (68.2%). We also know that 95.4% of the time our count will be between ± 2 standard deviations and that 99.97% of the time our count will be between ± 3 standard deviations.

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. Counts outside the warning limits indicate that something MAY be wrong. 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. We use 3σ 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.

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.

When patterns do show up in quality control charts, they are usually indicators of systematic error. For example:

- Multiple points outside two sigma
- Repetitive points (n out of n) outside one sigma
- Multiple points, in a row, on the same side of the mean
- Multiple points, in a row, going up or down.

The assumption is made that systematic error is present in our measurements, and that our statistical analysis has some potential for identifying its presence. However, industry assumption is that systematic error that is present is very small in comparison to random error.

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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.

COUNTER EFFICIENCY

A detector intercepts and registers only a fraction of the total number of radiations emitted by a radioactive source. The major factors determining the fraction of radiations emitted by a source that are detected include:

- The fraction of radiations emitted by the source which travel in the direction of the detector window
- The fraction emitted in the direction of the detector window which actually reach the window
- The fraction of radiations incident on the window which actually pass through the window and produce an ionization
- The fraction scattered into the detector window

All radiation detectors will, in principle, produce an output pulse for each particle or photon which interacts within its active volume. The detector then would be said to be

100 percent "efficient," because 100 percent of the activity was detected and reported. In practice, because of the factors outlined above, the actual (or total) activity emitted from the source is not detected. Therefore, there is only a certain fraction of the disintegrations occurring that results in counts reported by the detector. Using a calibrated source with a known activity, a precise figure can be determined for this fraction. 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. 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.

The detector efficiency gives us the fraction of counts detected per disintegration, or c/d. 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. Counts per minute (cpm) and disintegrations per minute (dpm) are the most common.

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).

(Equation 6)
$$E = \frac{cpm}{dpm} = \frac{c}{d}$$

The efficiency obtained in the formula above will be in fractional or decimal form. To calculate the *percent efficiency*, the fraction can be multiplied by 100. For example, an efficiency of 0.25 would mean 0.25×100 , or 25%.

Example 2.03-3

A source is counted and yields 2840 counts per minute. If the source activity is known to be 12,500 dpm calculate the efficiency and percent efficiency.

By algebraic manipulation, Equation 6 can be solved for the disintegration rate (see Equation 7). The system efficiency is determined as part of the calibration. When analyzing samples, a count rate is reported by the counting system. 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).

(Equation 7)
$$dpm = \frac{cpm}{E} \longrightarrow A_{dpm} = \frac{cpm}{E}$$

Example 2.03-4

A sample is counted on a system with a 30% efficiency. If the detector reports 4325 net counts per minute what is the activity of the sample in dpm?

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

(Equation 7)

$$CF = \frac{1}{E}$$

Example 2.03-5

An instrument has an efficiency of 18%. What is the correction factor?

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

2.03.14 *State the meaning of counting data reported as $x.xx \pm yy$.*

2.03.15 *Given counting results and appropriate formulas, report results to desired confidence level.*

ERROR CALCULATIONS

The error present in a measurement governed by a statistical model can be calculated using known parameters of that model. 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. 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. 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*.

In order to do this, the reported result should be in the format:

(Equation 9)

$$x.xx \pm yy (K \sigma)$$

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
σ	=	standard deviation at stated confidence level (CL)

Note: Use of $K\sigma$ is only required for confidence levels other than 68% (see Table 4). Therefore:

σ	=	$1 \times \sigma$	68% CL (optional)
1.64σ	=	$1.64 \times \sigma$	90% CL (sometimes used)
2σ	=	$1.96 \times \sigma$	95% CL (normally used)

For example, a measurement of **150 ± 34 dpm (2 σ)** 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 2σ).

The calculations of the actual range of error is based on the standard deviation for the distribution. In the normal (or Gaussian) distribution, the standard deviation of a single count is defined as the square root of the mean, or $\sigma = \sqrt{x}$. 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, $K \sigma$. 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). Common values for K include:

Table 4. Counting Error Multiples

Error	Confidence Level	K
Probable	50%	0.6745
Standard	68%	1.0000
9/10	90%	1.6449
95/100	95%	1.9600
99/100	99%	2.5750

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 $x.xx \text{ dpm} \pm yy \text{ dpm} (2 \sigma)$. 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.

The simple standard deviation (σ) 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.

(Equation 10)
$$\sigma = K \sqrt{\frac{R}{T}}$$

Example 2.03-6

The count rate for a sample was 250 cpm. Assume 10 minute counting time, zero background counts and a 25% efficiency. Report sample activity at a 95% C.L.

2.03.16 State the purpose of determining background.

BACKGROUND

Determination of Background

Radioactivity measurements cannot be made without consideration of the background. *Background*, or background radiation, is the radiation that enters the detector concurrently with the radiation emitted from the sample being analyzed. This radiation can be from natural sources, either external to the detector (i.e., cosmic or terrestrial) or radiation originating inside the detector chamber that is not part of the sample.

In practice, the total counts are recorded by the counter. This total includes the counts contributed by both the sample and the background. 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*. 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). This relationship is seen in the following equation:

(Equation 11) $R_S = R_{S+B} - R_B$

where:

R_S	=	net sample count rate (cpm)
R_{S+B}	=	gross sample count rate (cpm)
R_B	=	background count rate (cpm)

The background is determined as part of the system calibration by counting a background (empty) planchet for a given time. 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.

(Equation 12) $R_B = \frac{N_B}{T_B}$

where:

R_B	=	background count rate (counts per time, i.e., cpm)
N_B	=	gross counts, background
T_B	=	background count time

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.

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. If system background is above this limit the detector should be cleaned or replaced.

Reducing Background

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

Background originating inside the detector chamber can be, for the most part, more easily controlled. The main contributors of this type of background are:

- Radiation emitted from detector materials
- Radioactive material on inside detector surfaces
- Radioactive material on the sample slide assembly
- Contamination in or on the sample planchet or planchet carrier

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. However, the contribution to background from this source is negligible, but should nonetheless be acknowledged.

Radioactive material can be transferred from contaminated samples to the inside surfaces of the detector chamber during counting. This usually occurs when samples having gross amounts of material on them are counted in a low background system. During the insertion and withdrawal of the sample into the detector chamber, loose material can be spread into the chamber. In order to prevent this, these samples should be counted using a field survey instrument or a mini-scaler. 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.

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.

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. The slide assembly should also be cleaned on a routine basis (i.e., weekly).

When loading and unloading samples into and from planchets, material from the samples can be spread to the planchet and/or the carrier. Most smears and air samples are 47-mm diameter and are counted in a planchet that is almost the same size. The planchet is placed in a carrier which surrounds and supports the planchet and allows for automatic sample exchange by the counting system. When a sample is counted, the entire carrier is placed under the detector window inside the detector chamber. Any contamination on the carrier (or in the planchet) is counted with, and attributed to, the sample.

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. Care should be taken when loading and unloading samples such that material remains on the sample media.

2.03.17 *State the method and requirements for determining background for counting systems at your site.*

(Insert site-specific information here.)

2.03.18 *State the purpose of performing planchet maintenance.*

PLANCHET MAINTENANCE

Planchets and carriers should be inspected, cleaned, and counted on a routine basis. All in-use planchets and carriers must read less than established site limits. Planchets exceeding these limits should be decontaminated and recounted as necessary.

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.

2.03.19 *State the method and requirements for performing planchet maintenance for counting systems at your site.*

PROPAGATION OF ERROR

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. 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.

(Equation 13)
$$e_S = \sqrt{e_{S+B}^2 + e_B^2}$$

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

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* (Φ_S):

(Equation 14)
$$K\sigma_S = K\sqrt{\frac{R_{S+B}}{T_S} + \frac{R_B}{T_B}}$$

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)

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.

Example 2.03-7

An air sample is counted and yields 3500 counts for a 2-minute count period. The system background is 10 cpm determined over a 50-minute count time. Determine the error in the sample and report the net count rate to 95% confidence level.

If the sample counting time and the background counting time is the same, the formula can be simplified even more to:

(Equation 15)
$$K\sigma_s = K\sqrt{\frac{R_{S+B} + R_B}{T}}$$

Example 2.03-8

A long-lived sample is counted for one minute and gives a total of 562 counts. A one minute background gives 62 counts. Report net sample count rate to 95% CL.

2.03.20 Explain the methods used to improve the statistical validity of count room measurements.

IMPROVING STATISTICAL VALIDITY OF COUNT ROOM MEASUREMENTS

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. The standard deviation is calculated here in terms of count rate.

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

R_{S+B} is the sample count rate. We really have no control over this.

R_B is the background count rate. We **do** have some control over this. On any counting equipment the **background should be maintained as low as possible**. 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. This really becomes an issue when counting samples for free release or environmental samples. However, **some reduction in error can be obtained by increasing the background counting time**, as discussed below.

T_B and T_S are the background and sample counting times, respectively. These are the factors that we have absolute control over. 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. 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).

The total counting time required depends upon both the sample and background count rates. For high sample activities the sample count time can be relatively short compared

to the background count time. For medium count rates we must increase the sample count time in order to increase precision. As the sample activity gets even lower, we approach the case where we must devote equal time to the background and source counts. 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. However, we must never count a sample for a period of time longer than that of the system background.

In summary, by minimizing the potential error present, we improve statistical validity of our measurements.

2.03.21 *Define "detection limit," and explain the purpose of using detection limits in the analysis of radioactive samples.*

DETECTION LIMITS

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

The two parameters of interest for a detector system with a background response greater than zero are (see Figure 6):

- L_C Critical detection level: the response level at which the detector output can be considered "above background"
- L_D Minimum significant activity level, i.e., the activity level that can be seen with a detector with a fixed level of certainty

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. For these calculations, two types of statistical counting errors must be considered quantitatively in order to define acceptable probabilities for each type of error:

- Type I -** occurs when a detector response is considered above background when in fact it is not (associated with L_C)
- Type II -** occurs when a detector response is considered to be background when in fact it is greater than background (associated with L_D)

I = Probability of Type I error
 II = Probability of Type II error

B = Background
 L_C = Critical detection level
 L_D = Minimum significant activity level

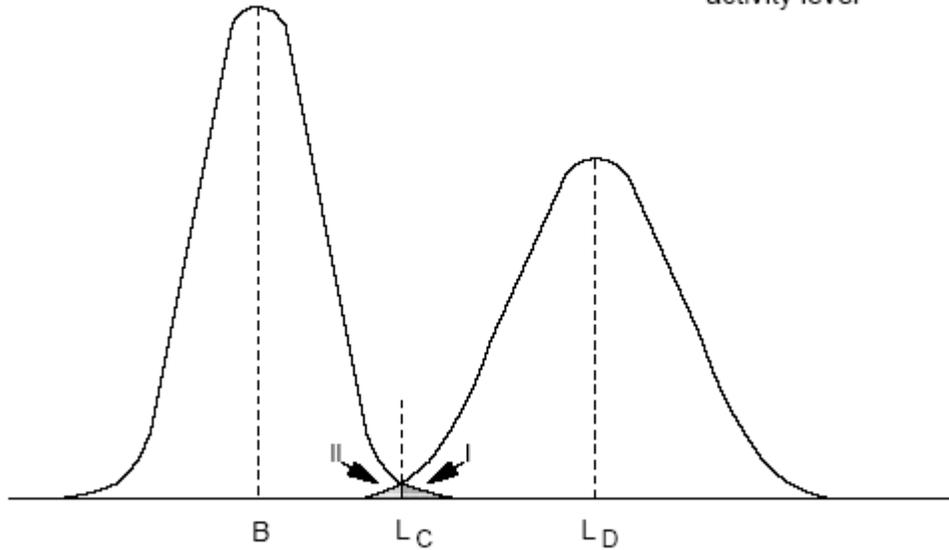


Figure 6. Errors in Detection Sensitivity

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. The two values would be derived using the equations $L_C = k\sigma_B$ and $L_D = k^2 + 2k\sigma_B$, respectively. 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, if for example then $k = 1.645$ and the two equations can be written as:

(Equation 16)
$$L_C = 1.645 \sqrt{\frac{R_B}{T_B} + \frac{R_B}{T_S}}$$

(Equation 17)
$$L_D = 2.71 + 3.29 \sqrt{\frac{R_B}{T_B} + \frac{R_B}{T_S}}$$

where:

L_C	=	Critical detection level
L_D	=	<i>a priori</i> detection limit [minimum significant activity level]
k	=	Poisson probability sum for I and II (assuming I and II probabilities are equal)
R_B	=	background count rate
T_B	=	background count time
T_S	=	sample count time

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. In other words, it is the smallest amount of activity that can be detected at a 95% confidence level. When stating the detection capability of an instrument, this value should be used.

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." This value (L_C) should be used when actually counting samples or making direct radiation measurements. Any response above this level should be counted as positive and reported as valid data. This will ensure 95% detection capability for L_D .

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:

(Equation 18)
$$L_C = 2.32 \sqrt{\frac{R_B}{T}}$$

(Equation 19)
$$L_D = 2.71 + 4.65 \sqrt{\frac{R_B}{T}}$$

where:	L_C	=	Critical detection level (count rate)
	L_D	=	Minimum significant activity level (count rate)
	k	=	same as above; 1.645 for 95% CL
	R_B	=	background count rate
	T	=	count time (sample and background)

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).

The critical detection level, L_C , is used when reporting survey results. It is used to say that at a 95% confidence level, samples above this value are radioactive. This presupposes, then, that 5% of the time clean samples will be considered radioactive.

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. This value is used to determine minimum count times based on release limits and airborne radioactivity levels. 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.

Example 2.03-9

A background planchet is counted for 50 minutes and yields 16 counts. Calculate the critical detection level and the minimum significant activity level for a 0.5 minute sample count time.

2.03.22 *Given the formula and necessary information, calculate detection limit values for counting systems at your site.*

(Insert site-specific information here.)

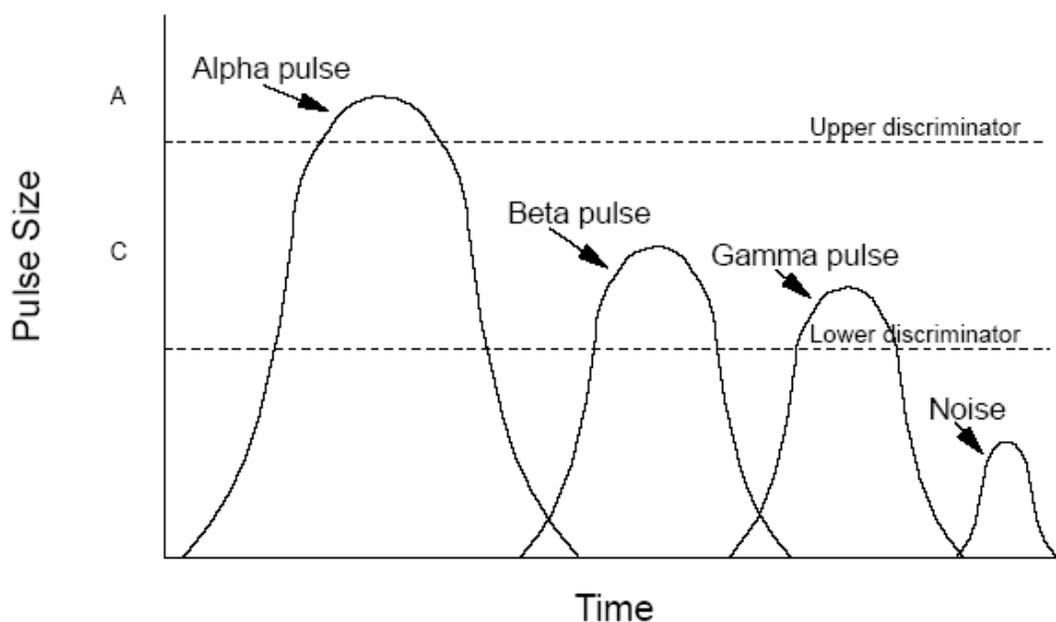
2.03.23 State the purpose and method of determining crosstalk.

CROSSTALK

Discrimination

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. Discrimination is accomplished by establishing two thresholds, or *windows*, which can be set in accordance with the radiation energies of the isotopes of concern. Recall that the pulses generated by alpha radiation will be much larger than those generated by beta or gamma. This makes the discrimination between alpha and beta-gamma possible. Beta and gamma events are difficult to distinguish; hence, they are considered as one and the same type by such counting systems.

In practice, the lower window is set such that electronic noise and ultra-low-energy photon events are filtered out. Any pulse generated whose size is greater than the setting for the lower window is considered an event, or a *count*. The upper window is then set such that any pulses which surpass the upper discriminator setting will be considered an alpha count (see Figure 7).



$$* C - A = B$$

Figure 7. Pulse-height Discrimination

For output purposes, the system routes each count to a series of *channels* which simply keep a total of the counts routed to them. Channel A is for alpha counts, Channel B is beta-gamma counts, and 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. 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. 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 $B = C - A$.

Origin of Crosstalk

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. The system cannot really tell what type of radiation has generated the pulse. 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.

Alpha particles entering the detector chamber generally are attenuated by the detector fill-gas because of their high LET, thereby producing a large pulse.

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. High energy beta particles can still retain some of their energy even after having produced a pulse while traversing the detector volume. 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. These two pulses can be so close together that the detector sees them as one large pulse. 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. The result is that alpha activity can be reported for a sample when in fact there was little or no alpha present. 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*.

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. If high energy beta radiations are involved, a significant portion of them could be counted as alpha events if the setting is too low. If the setting is too high, lower-energy alpha events could be counted as beta-gamma. Typically, the setting of the discriminator will usually be some "happy medium." A discussion of how this can be dealt with is in order.

Calibration Sources and Crosstalk

For calibrations of Tennelec counting systems, the manufacturer provides the following general recommendations for discriminator settings: First, using a Strontium-90 beta source, set the upper (α) discriminator such that there is 1% beta-to-alpha crosstalk.

Then, using a Polonium-210 alpha source, set the $\alpha+\beta$ discriminator such that there is less than 3% alpha-to-beta crosstalk.

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. Wherever possible they should be a pure emitter of the radiation of concern.

For beta-gamma sources the most popular isotope in radiation protection is Sr-90. It has a relatively long half-life of 29.1 years, but emits betas of only 546 keV. 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. Y-90 decays to Zirconium-90m which emits a 2.186 MeV gamma almost instantaneously to become stable. The daughters reach equilibrium with the strontium parent within a number of hours after source assay. Hence, for every Sr beta emitted a Y beta is also emitted, thereby doubling the activity. These sources are often listed as

Sr/Y-90 for obvious reasons. This makes Sr/Y-90 sources an excellent choice and are used by many sites for calibrations and performance testing.

Po-210 is essentially a pure alpha emitter. This is primarily the reason why it is recommended for calibrations and performance testing. It yields a strong alpha, but it also has a short half-life. A comparison of some alpha emitters is given in Table 5.

Table 5. Alpha Emitters

Isotope	Half-Life	Energy (MeV)
Po-210	138.38 days	5.3044
Pu-239	2.4E4 years	5.156, 5.143, 5.105
Ra-226	1.60E3 years	4.78, 4.602
Th-230	7.54E4 years	4.688, 4.621
Natural U	4.4E9 years (avg.)	4.2 (avg.)

2.03.24 *State the criteria for acceptable values of crosstalk for counting systems at your site.*

(Insert site-specific information here.)

2.03.24 State the criteria for acceptable values of crosstalk for counting systems at your site.

VOLTAGE PLATEAUS

Very simply put, a *voltage plateau* is a graph that indicates a detector's response to an isotope with variations of high voltage. The x-axis represents the high voltage and the y-axis the response (i.e., counts). The resulting curve gives an indication of detector quality, and can indicate problems with the counting gas should they be present. The curve can also be used to determine the optimum operating high voltage for the system.

Most automatic low-background counting systems provide several different analysis modes. These modes count samples at certain pre-determined voltages. Counting systems generally provide three analysis modes:

- ALPHA ONLY
- ALPHA THEN BETA
- ALPHA AND BETA (SIMULTANEOUS)

There are usually two voltage settings used in conjunction with these analysis modes:

- **Alpha** voltage (lower)
- [Alpha plus] **Beta** voltage (higher)

Recall that in a proportional counter the amount of voltage determines the amount of gas multiplication. 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. 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.

In the ALPHA ONLY mode, the sample is counted once, at the alpha voltage. Counts may appear in either the A or B channels. 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.

In the ALPHA THEN BETA mode, the sample is counted twice. The first count interval determines the alpha counts using the alpha voltage. The second count is done at the beta voltage. 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. For this reason, the A and B counts are summed during both counting intervals to attain the total counts. The separation of alpha and beta-gamma counts is then calculated and reported according to the following formula:

(Equation 20)

$$\alpha = \frac{A_1 + B_1}{CF_\alpha}$$

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

where:

α	=	reported gross alpha counts
β	=	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_α	=	alpha correction factor (ratio of alpha efficiency at alpha voltage to efficiency at beta voltage)

In the ALPHA AND BETA (SIMULTANEOUS) mode, the sample is counted once using the beta voltage. Alpha events are reported in the A channel, while beta-gamma counts are reported in the B channel. This is the mode used most often.

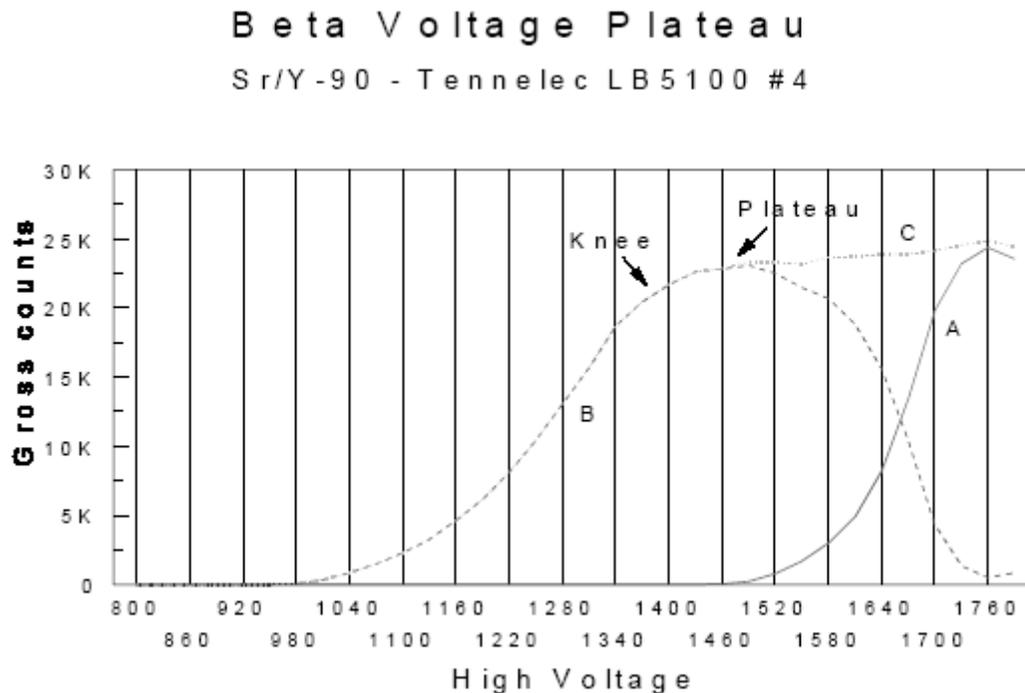
As can be seen, the setting of the two voltages will have a direct impact on the number of counts reported for a given sample. The determination of what these voltage settings should be must be done such that the optimum performance of the detector is obtained for those voltage regions. This is the purpose of a plateau.

2.03.26 *State the method of performing a voltage plateau on counting systems at your site.*

(Insert site-specific information here.)

In conjunction with initial system setup and calibration by the vendor, two voltages plateaus are performed--alpha voltage and beta voltage. For P-10 gas the alpha plateau is started at about 400 volts and the beta plateau at about 900 volts. Alpha and beta plateaus are defined by the isotope being used and not by the channel being used to accumulate the counts. More appropriately, the gross counts are accumulated and plotted for each type of isotope. 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. This is repeated until the end of the range is reached, typically about 1800 volts.

With the high voltage set at the starting point, few or no counts are observed because of insufficient ion production within the detector. 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. There will be a high voltage setting where the increase in counts levels off (see Figure 8). This area is the detector plateau. Further increases in high voltage result in little change in the overall count rate. The plateau should remain flat for at least 200 volts using a Sr/Y-90 source, and this indicates the plateau length. 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.



The region where the counts level off is called the *knee* of the plateau. 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%. 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. 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.

SUMMARY

This lesson addressed the measures used to minimize error and the fundamentals of binomial statistics, as well as the application of these fundamentals in a nuclear counting environment. Completion of the unit does not qualify the student to perform any tasks independently.

EXAMPLE PROBLEM SOLUTIONS

2.03-1

σ	\bar{x}	$\Sigma(x - \bar{x})^2$
10.31	142.9	1062.9

Therefore, the mean of the set is found to be 142.9, and the standard deviation is 10.31.

2.03-2

$$X^2 = \frac{1062.9}{142.9} = 7.44$$

2.03-3

$$E = \frac{2840}{12500}$$

$$E = 0.2272$$

$$0.2272 \times 100 = 22.72\%$$

2.03-4

$$A = \frac{4325}{0.3} = 14416.7 \text{ dpm}$$

2.03-5

$$CF = \frac{1}{0.18} = 5.\bar{5}$$

2.03-6

$$2\sigma = 1.26\sqrt{\frac{250}{10}} = 1.96\sqrt{25}$$

$$2\sigma = 1.96(5) = 9.8$$

$$\frac{250cpm}{0.25cld} = 1000dpm$$

$$\frac{9.8cpm}{0.25cld} = 39dpm$$

2.03-7

$$\frac{3500counts}{2minutes} = 1750 - 10 = 1740cpm$$

$$\sigma_s = \sqrt{\frac{1750}{2} + \frac{0.2}{50}} = 29.6$$

$$2\sigma_s = 29.6 \times 1.96 = 58$$

$$R_{S+B} = \frac{3500counts}{2minutes} = 1750cpm$$

$$R_B = \frac{10counts}{50minutes} = 0.2cpm$$

$$R_S = 1749.8cpm$$

$$T_S = 2minutes$$

$$T_B = 50minutes$$

Therefore, the net count rate should be reported as:

$$500 \pm 49cpm(2\sigma)$$

2.03-8

$$2\sigma_s = 1.96\sqrt{\frac{562 + 62}{1}}$$

$$2\sigma_s = 1.96\sqrt{624}$$

$$2\sigma_s = 1.96(24.98)$$

$$2\sigma = 49$$

$$R_s = 562 - 62 = 500\text{cpm}$$

Therefore, the net sample count rate and associated error is:

$$500 \pm 49\text{cpm}(2\sigma)$$

2.03-9

$$L_C = 1.645\sqrt{\frac{0.32}{50} + \frac{0.32}{0.5}}$$

$$L_C = 1.645\sqrt{0.0064 + 0.64}$$

$$L_C = 1.645\sqrt{0.6464}$$

$$L_C = 1.32\text{cpm}$$

$$L_D = 2.71 + 3.29\sqrt{\frac{0.32}{50} + \frac{0.32}{0.5}}$$

$$L_D = 2.71 + 3.29(0.804)$$

$$L_D = 5.36\text{cpm}$$

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.

INTRODUCTION

Radiation dosimetry is the branch of science that attempts to quantitatively relate specific measures made in a radiation field to chemical and/or biological changes that the radiation would produce in a target. Dosimetry is essential for quantifying the incidence of various biological changes as a function of the amount of radiation received (dose-effect relationships), for comparing different experiments, for monitoring the radiation exposure of individuals, and for surveillance of the environment.

External dosimetry is the science dealing with the measurement of a radiation field incident to the body and the evaluation of the equivalent dose resulting from energy deposited within the body by radiation. External dose is usually a derived or inferred quantity since it is not possible to directly measure the exact dose to any organ or tissue. Any measurement must be compared to a known quantity to derive dose and equivalent dose. This process is called "calibration".

Internal dosimetry is the analysis and measurement of radionuclides in humans or bioassay samples and the evaluation of intakes and doses from those measurements. It involves evaluation of bioassay data, evaluation of the intake, distribution, retention, and elimination of radionuclides, and evaluation of various absorbed doses and equivalent dose quantities. Internal dosimetry is inherently indirect in nature. It is not possible to determine the exact organ absorbed dose, equivalent dose or effective dose in a living human being resulting from an intake of radioactive materials. Internal dose is usually a derived or inferred quantity, obtained by evaluation of indirect measurements and computational models. This is particularly true for alpha- and beta-emitting radionuclides in the body which have low photon emission abundances. Direct measurements of internalized photon-emitting radionuclides in organs also may be difficult because of attenuation and scattering by overlying tissues.

The capability to accurately measure and analyze radioactive materials and workplace conditions, and determine personnel radiation exposure is fundamental to the safe conduct of radiological operations. Accordingly, DOE shall ensure radiological measurements, analyses, worker monitoring results and estimates of public exposures are accurate and appropriately made. 10 CFR 835 prescribes the requirements for both external and internal dose monitoring.

It is the responsibility of all workers to wear personnel monitoring devices where required by Radiological Work Permits, signs, procedures or by radiological control personnel. They are also expected to report immediately the loss, damage or unexpected exposure of personnel monitoring devices or off-scale readings of self-reading dosimeters to the Radiological Control Organization (RCO). All employees are expected to keep track of their radiation exposure status and avoid exceeding radiological Administrative Control Levels. Additionally, all should notify the RCO

of off-site occupational radiation exposures so that worker dosimetry records can be updated.

References:

1. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5th 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".

DOSIMETRY TERMS*Absorbed Dose (D):*

Energy absorbed by matter from ionizing radiation per unit mass of irradiated material at the place of interest in that material. The absorbed dose is expressed in units of rad (or gray) (1 rad = 0.01 gray).

Equivalent Dose (H_T):

The product of average absorbed dose ($D_{T,R}$) in rad (or gray) in a tissue or organ (T) and a radiation (R) weighting factor (w_R). For external dose, the equivalent dose to the whole body is assessed at a depth of 1 cm in tissue; the equivalent dose to the lens of the eye is assessed at a depth of 0.3 cm in tissue, and the equivalent dose to the extremity and skin is assessed at a depth of 0.007 cm in tissue. Equivalent dose is expressed in units of rem (or Sv).

Whole Body:

For the purposes of external exposure, head, trunk (including male gonads), arms above and including the elbow, or legs above and including the knee.

Extremity:

Hands and arms below the elbow or feet and legs below the knee.

Committed Equivalent Dose ($H_{T,50}$):

The equivalent dose calculated to be received by a tissue or organ over a 50-year period after the intake of a radionuclide into the body. It does not include contributions from radiation sources external to the body. Committed equivalent dose is expressed in units of rem (or Sv).

Radiation Weighting Factor (w_R):

A modifying factor used to calculate the equivalent dose from the average tissue or organ absorbed dose; the absorbed dose (expressed in rad or gray) is multiplied by the appropriate radiation weighting factor. The radiation weighting factors to be used for determining equivalent dose in rem are as follows:

equivalent dose to the remainder organs and tissues. Committed effective dose is expressed in units of rem (or Sv).

Total Effective Dose (TED):

The sum of the effective dose (for external exposures) and the Committed Effective Dose (for internal exposures).

Annual Limit on Intake (ALI):

The derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man (ICRP Publication 23) that would result in a committed effective dose of 5 rems (0.05 sieverts (Sv)) (1 rem = 0.01 Sv) or a committed equivalent dose of 50 rems (0.5 Sv) to any individual organ or tissue. ALI values for intake by ingestion and inhalation of selected radionuclides are based on International Commission on Radiological Protection Publication 68, Dose Coefficients for Intakes of Radionuclides by Workers, published July, 1994 (ISBN 0 08 042651 4).

Derived Air Concentration (DAC):

For the radionuclides listed in appendix A of this part, the airborne concentration that equals the ALI divided by the volume of air breathed by an average worker for a working year of 2000 hours (assuming a breathing volume of 2400 m³). For the radionuclides listed in appendix C of this part, the air immersion DACs were calculated for a continuous, non-shielded exposure via immersion in a semi-infinite cloud of radioactive material. Except as noted in the footnotes to appendix A of this part, the values are based on dose coefficients from International Commission on Radiological Protection Publication 68, Dose Coefficients for Intakes of Radionuclides by Workers, published July, 1994 (ISBN 0 08 042651 4) and the associated ICRP computer program, The ICRP Database of Dose Coefficients: Workers and Members of the Public, (ISBN 0 08 043 8768).

Bioassay:

The determination of kinds, quantities, or concentrations, and, in some cases, locations of radioactive material in the human body, whether by direct measurement or by analysis, and evaluation of radioactive materials excreted or removed from the human body.

In Vivo:

A direct bioassay measurement of radioactivity in living tissue, for example, a whole body count or chest count.

In Vitro:

The bioassay measurement of radioactivity by means of internal representative sampling in order to estimate the radioactivity in tissue. Examples are analysis of urine and fecal collections.

Background:

Radiation from: naturally occurring radioactive materials which have not been technologically enhanced, cosmic sources, global fallout as it exists in the environment (such as from the testing of nuclear explosive devices), radon and its progeny in concentrations or levels existing in buildings or the environment which have not been elevated as a result of current or prior activities, and consumer products containing nominal amounts of radioactive material or producing nominal amounts of radiation.

Declared Pregnant Worker:

A woman who has voluntarily declared to her employer, in writing, her pregnancy for the purpose of being subject to the occupational exposure limits to the embryo/fetus as provided in 10 CFR 835.206. This declaration may be revoked, in writing, at any time by the declared pregnant worker.

DOE LIMITS

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.

Annual dose limits are based on a calendar year (January 1st through December 31st). For assigning internal doses received from intakes (committed equivalent dose and committed effective 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.

2.04.01	<i>Identify the DOE external exposure limits for occupational workers.</i>
---------	--

General Employees

General employees are DOE employees or DOE contractors. A Radiological Worker is a general employee whose job assignment involves operation of radiation producing devices or working with radioactive materials, or who is likely to be routinely occupationally exposed above 0.1 rem (0.001 sievert) per year total effective dose.

Radiological workers from other DOE or DOE contractor facilities may receive occupational exposure to ionizing radiation as a radiological worker if they:

- Provide a record of current Radiological Worker I or II standardized core training,
- Receive site-specific Radiological Worker I or II training at the facility where they will be working, and
- Provide their radiation dose record or a written estimate for the current year.

Table 2 lists the various legal limits for exposure to ionizing radiation. There are four general categories listed: whole body, lens of the eyes, extremities and organ/tissue/skin. These limits are also covered in 10 CFR 835.208 and the Radiological Control Standard (RCS). Exposures should be well below the limits in this table and maintained as low as reasonably achievable.

Table 2 - Summary of Dose Limits

TYPE OF EXPOSURE	ANNUAL LIMIT
General Employees: Whole body (internal + external) Lens of Eye Extremity (hands and arms below the elbow: feet and legs below the knee) Any organ or tissue (other than lens of eye) and skin	5 rem (0.05 sievert) 15 rem (0.15 sievert) 50 rem (0.5 sievert) 50 rem (0.5 sievert)
Declared Pregnant Worker Embryo/Fetus	0.5 rem (0.005 sievert) Per gestation period
Minors (under age 18) and Students Whole body (internal + external) Extremity/Skin Lens of Eye	0.1 rem (0.001 sievert) 5 rem (0.05 sievert) 1.5 rem (0.001 sievert)
Members of the public: Whole body (internal + external)	0.1 rem (0.001 sievert)

Notes:

1. Internal dose to the whole body should be calculated as committed effective dose. The committed effective dose is the resulting dose committed to the whole body from internally deposited radionuclides over a 50-year period after intake.
2. The annual limit of exposure to "any organ or tissue" is based on the committed dose to that organ or tissue resulting from internally deposited radionuclides over a 50-year period after intake plus any external effective dose to that organ during the year.
3. Exposures due to background radiation, therapeutic and diagnostic medical procedures, and participation in medical research programs should not to be included in either personnel radiation dose records or assessment of dose against the limits in this table.

Minors//Public

Minors are individuals less than 18 years of age. The public are defined as individuals not occupationally exposed to radiation or radioactive materials. An individual is not a "member of the public" during any period in which the individual receives an occupational dose. Occupational dose is an individual's dose due to exposure to ionizing radiation (external and internal) as a result of that individual's work assignment. Occupational dose does not include exposure received as a medical patient, background radiation, or participation in medical research programs. The DOE limit for exposure to minors and the public is stated in 10 CFR 835.207 and 835.208 and are listed in Table 2.

2.04.02	<i>Identify the DOE limits established for the embryo/fetus of a female occupational worker.</i>
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Embryo/Fetus of Declared Pregnant Workers

After a female general employee voluntarily notifies her supervisor in writing that she is pregnant, for the purposes of embryo/fetal dose protection, she should be considered a declared pregnant worker. The employer should provide the option of a mutually agreeable reassignment of work tasks, without loss of pay or promotional opportunity, such that further occupational radiation exposure is unlikely.

For a declared pregnant worker who chooses to continue radiological work:

- The dose limit for the embryo/fetus for the entire gestation period (from conception to birth) is 0.5 rem (0.005 sievert) {10 CFR 835.206}.
- Efforts should be made to avoid exceeding 0.05 rem (0.0005 sievert) per month to the pregnant worker {10 CFR 835.206}.

If the dose is likely to approach 0.05 rem/month (0.0005 sievert/month), additional dosimetry will be assigned to monitor the dose to the embryo/fetus.

If the dose to the embryo/fetus is determined to have already exceeded 0.5 rem (0.005 sievert) when a worker notifies her employer of her pregnancy, the worker should not be assigned to tasks where additional occupational radiation exposure is likely during the remainder of the gestation period.

Emergency Exposures

Emergency Exposure Situations

For emergency situations, general employees could be allowed to exceed specified dose limits. The level of exposure permitted will depend upon the severity of the emergency situation. Exposures up to 2 times the annual dose limits could be permitted to protect against property loss. Higher exposures, up to 5 times the annual dose limits or greater, could be permitted to save lives and protect public health. The potential amount of exposure to rescue personnel should be evaluated, and an exposure objective should be established for the rescue mission.

The DOE requires that the details of any exposure in excess of the annual dose limits be documented in the occupational exposure record of the affected employee. In addition, the incident must be investigated and the results reported to DOE. Departmental requirements for occurrence reporting and processing provide a mechanism for such investigations and reports. The employee must not be allowed to receive further exposure until approval is first obtained from the contractor management and responsible DOE field organization. Also, the employee must receive counseling from the appropriate health experts regarding the consequences of receiving additional occupational exposure that year and the affected employee must agree, before returning to radiological work.

Operations which have been suspended as a result of a dose in excess of the limits specified in § 835.202, except those received in accordance with § 835.204, may only be resumed with the approval of the DOE. The operation that caused the exposure must cease pending a finding by DOE that the conditions that caused the exposure had been eliminated.

Planned Special Exposures

A planned special exposure may be authorized for a radiological worker to receive doses in addition to and accounted for separately from the doses received under the normal occupational limits specified in Sec. 835.202(a) provided that each of the following conditions are satisfied:

1. The planned special exposure is considered only in an exceptional situation when alternatives that might prevent a radiological worker from exceeding the limits in 835.202(a) are unavailable or impractical;
2. The contractor management (and employer, if the employer is not the contractor) specifically requests the planned special exposure, in writing; and

3. Joint written approval is received from the appropriate DOE Headquarters program office and the Secretarial Officer responsible for environment, safety, and health matters.

Prior to requesting an individual to participate in an authorized planned special exposure, the individual's dose from all previous planned special exposures and all doses in excess of the occupational dose limits should be determined. An individual should not receive a planned special exposure that, in addition to these doses determined, would result in a dose exceeding:

1. In a year, the numerical value of the dose limits established in 835.202(a); or
2. Over the individual's lifetime, five times the numerical value of the dose limits provided in 835.202(a).

Prior to a planned special exposure, written consent should be obtained from each individual involved. Each individual consent should include:

1. The purpose of the planned operations and procedures to be used;
2. The estimated doses and associated potential risks and specific radiological conditions and other hazards which might be involved in performing the task; and
3. Instructions on the measures to be taken to keep the dose ALARA considering other risks that may be present.

Records of the conduct of a planned special exposure should be maintained and a written report submitted within 30 days after the planned special exposure to the approving organizations. The dose from these planned special exposures is not to be considered in controlling future occupational dose as part of the normal occupational dose of the individual under 835.202(a).

Equivalency of Dosimetric Terms

Under certain 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, it is not clear as to how to apply using different dose coefficients and weighting factors to calculate the overall cumulative total effective dose for workers. Accordingly DOE has stated that, for the purpose of compliance with 10 CFR 835.1(b)(1), DOE considers the following terms to be equivalent:

Table 3 Equivalency of Dosimetric Terms

Dosimetric Term Prior to 2007 Amendment to 10 CFR 835	DOE Amended Dosimetric Term
Committed effective dose equivalent	Committed effective dose
Committed dose equivalent	Committed equivalent dose
Cumulative total effective dose equivalent	Cumulative total effective dose
Deep dose equivalent	Equivalent dose to the whole body
Dose equivalent	Equivalent dose
Effective dose equivalent	Effective dose
Lens of the eye dose equivalent	Equivalent dose to the lens of the eye
Quality factor	Radiation weighting factor
Shallow dose equivalent	Equivalent dose to the skin or Equivalent dose to any extremity
Weighting factor	Tissue weighting factor
Total effective dose equivalent	Total effective dose

SITE ADMINISTRATIVE GUIDELINES

- 2.04.03 Identify the administrative exposure control guidelines at your site, including those for the:*
- a. Radiation worker*
 - b. Non-radiation worker*
 - c. Incidents and emergencies*
 - d. Embryo/Fetus*

Radiological Workers

(Insert site specific information here)

Non-radiation Worker

(Insert site specific information here)

Exposure from Incidents or Emergencies

(Insert site specific information here)

Embryo/Fetus of a Declared Pregnant Worker

(Insert site specific information here)

2.04.04	<i>Identify the requirements for a female radiation worker who has notified her employer in writing that she is pregnant.</i>
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SITE EXPOSURE REQUIREMENTS FOR THE UNBORN CHILD

(Insert site specific information here)

TYPES OF DOSIMETRY

As a result of irradiation, some solid substances undergo changes in some of their physical properties. These changes amount to storage of the energy from the radiation. Since the energy is stored, these materials can be used for dosimeters. The features that have been studied include:

Optical density changes

Optical density changes involve a change in the color of some types of plastics and glass. 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). Film badges, a type of optical density dosimetry, provides low range monitoring 10 mR to 10 R for personnel and high range monitoring 1 R to 1,000 R for accident readings.

Thermoluminescence

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. There are two categories of thermoluminescence.

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.

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.

The property of thermoluminescence of some materials is the main method used for personnel dosimeters at DOE facilities.

2.04.05	<i>Determine the theory of operation of a thermoluminescent dosimeter (TLD).</i>
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TLD OPERATION

TLDs use phosphorescence as their means of detection of radiation.

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. Electrons in the conduction band or in the band gap have more energy than the valence band electrons. Normally in a solid, no electrons exist in energy states contained in the band gap. This is a "forbidden region."

In some materials, defects in the material exist or impurities are added 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. (See figure 1) This energy is given up if the electron returns to the valence band.

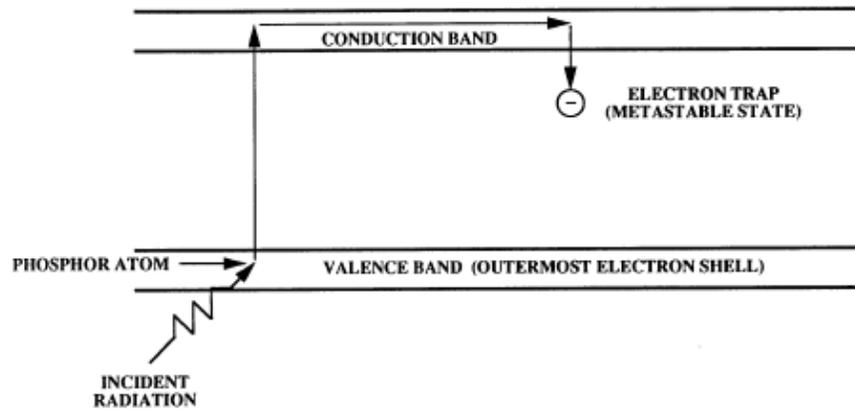


Figure 1 - Electron Entrapment

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)

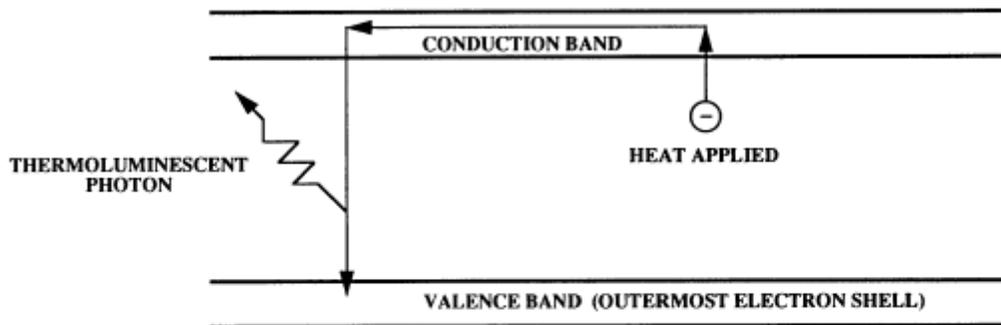


Figure 2 - Thermoluminescence

2.04.06 Determine how a TLD reader measures the radiation dose from a TLD.

TLD READER

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. The light output is detected and measured by a photomultiplier tube and a dose is then calculated. A typical basic TLD reader contains the following components: (See figure 3)

- Heater - raises the phosphor temperature

- Photomultiplier Tube - measures the light output
- Meter/Recorder - display and record data

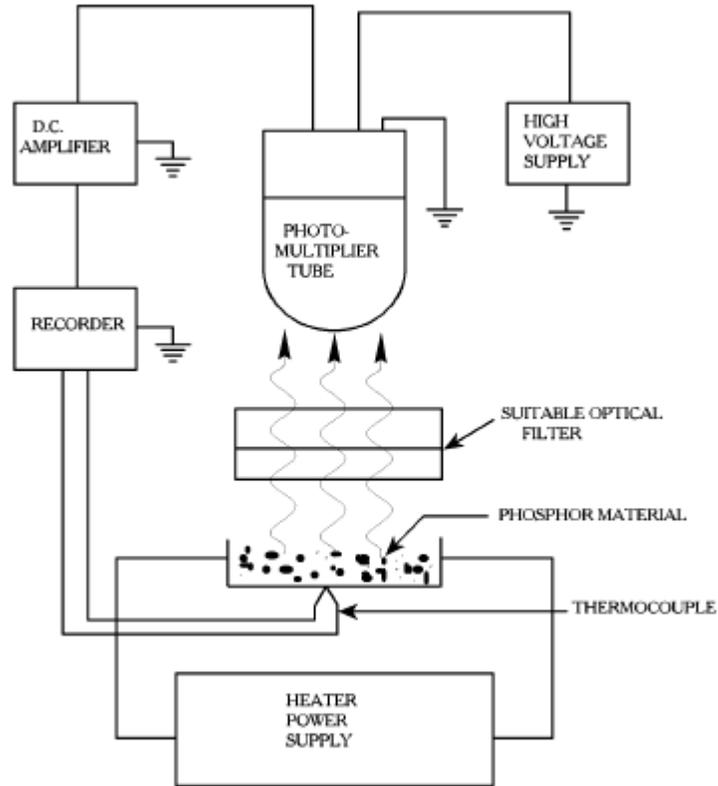


Figure 3 - TLD Reader

A glow curve can be obtained from the heating process. The light output from TL material is not easily interpreted. Multiple peaks result as the material is heated and 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. As heating continues, the electrons in deeper traps are released. This results in additional peaks. Usually the highest peak is used to calculate the dose. The area under the curve represents the radiation energy deposited on the TLD. A simple glow curve is shown in figure 4.

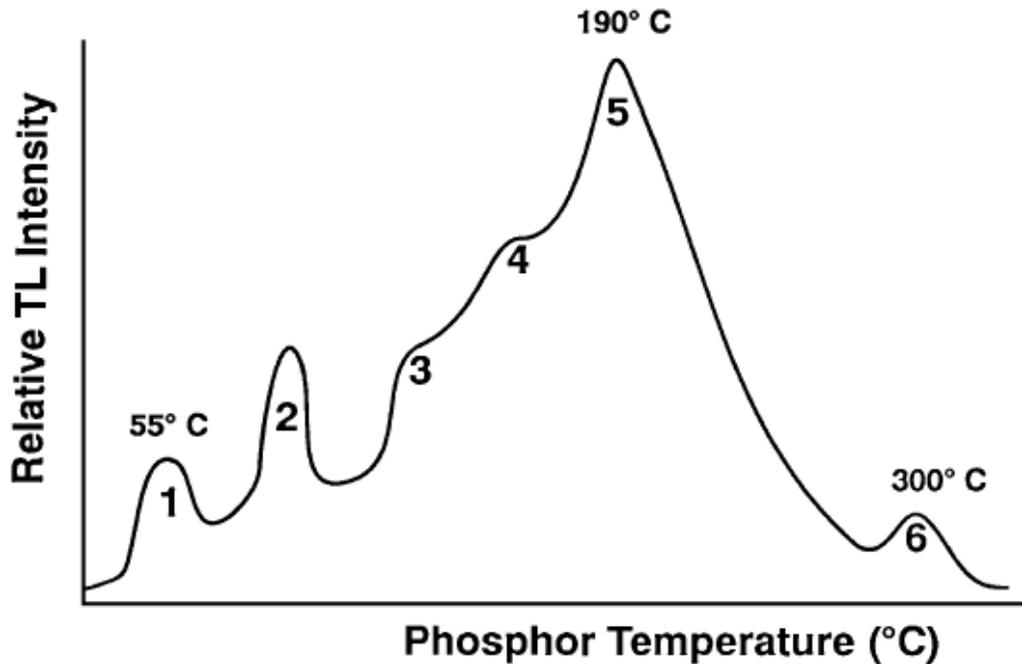


Figure 4 - Glow Curve

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.

2.04.07 Identify the advantages and disadvantages of a TLD compared to a film badge.

ADVANTAGES AND DISADVANTAGES OF TLDs

Advantages (as compared to film dosimeter badges) includes:

- Able to measure a greater range of doses
- Doses may be easily obtained
- They can be read on site instead of being sent away for developing
- Quicker turnaround time for readout
- Reusable

Disadvantages

- Each dose cannot be read out more than once
- The readout process effectively "zeroes" the TLD

2.04.08 Identify the types of beta-gamma TLDs used at your site.

SITE BETA/GAMMA TLDs

(Insert site specific material here)

2.04.09 Identify the types of neutron TLDs used at your site.

SITE NEUTRON TLDs

(Insert site specific material here)

DOE EXTERNAL DOSIMETRY REQUIREMENTS

Personnel dosimetry should be provided to and used by individuals as follows:

1. General employees who are expected to receive an effective dose to any portion of the whole body of 0.1 rem (0.001 sievert) or more in a year or an equivalent dose to the extremities, or organs and other tissues (including lens of the eye and skin) of 10 percent or more of the corresponding limits [835.402(a)(1)];
2. Declared pregnant workers who are expected to receive from external sources an equivalent dose of 0.05 rem (0.0005 sievert) or more to the embryo/fetus during the gestation period [835.402(a)(2)];
3. Occupationally exposed minors likely to receive from external sources an effective dose in excess of 50% of the limits [835.402(a)(3)];
4. Members of the public who enter the controlled area and are likely to receive an effective dose of 0.05 rem (0.0005 sievert) or more in a year [835.402(a)(4)]; and
5. Individuals entering a high or very high radiation area radiation area [835.402(a)(5)].

Neutron dosimetry shall be provided when an individual is likely to exceed the applicable threshold provided above due to neutron radiation [835.402(b)].

Dosimeters should be issued only to individuals knowledgeable of their proper use and worn only by those to whom the dosimeters were issued.

To minimize the number of individuals in the dosimetry program, the issuance of dosimeters is discouraged to other than individuals entering radiological areas where there is a likelihood of external exposure in excess of the monitoring thresholds established in Article 511.1 of the Radiological Control Standard. Although issuing dosimeters to individuals who are not occupationally exposed to radiation can appear as a conservative practice, it creates the impression that the wearers are occupationally exposed to radiation. Implementation of an unnecessarily broad dosimetry program is not an acceptable substitute for development of a comprehensive workplace monitoring program.

Individuals should return dosimeters for processing as scheduled or upon request, and should be restricted by line management from continued radiological work until dosimeters are returned.

Individuals should wear their primary dosimeters on the chest area, on or between the waist and the neck, or in the manner prescribed by radiological control procedures or work authorizations.

Film dosimeters should not be worn or taken off-site unless specifically authorized by the Radiological Control Manager or designee.

The practice at some facilities of taking thermoluminescent dosimeters (TLDs) off-site is discouraged and should not be implemented where not in place.

Individuals should not wear dosimeters issued by their resident facilities while being monitored by a dosimeter at another facility unless authorized by the Radiological Control Manager or designee. Individuals should not expose their dosimeters to security X-ray devices, excessive heat, or medical sources of radiation.

An individual whose dosimeter is lost, damaged, or contaminated should place work in a safe condition, immediately exit the area, and report the occurrence to the Radiological Control Organization. Reentry of the individual into radiological areas should not be made until a review has been conducted and management has approved reentry.

2.04.10	<i>Determine the requirements for use of TLDs used at your site.</i>
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SITE REQUIREMENTS FOR USE OF TLDs

(Insert site specific material here)

2.04.11 Determine the principle of operation, and the types used, for the personnel neutron dosimeters used at your site.

SITE PERSONNEL NEUTRON DOSIMETERS

(Insert site specific material here)

POCKET AND ELECTRONIC DOSIMETERS

Pocket and electronic dosimeters are supplemental dosimeters that provide real-time indication of exposure to radiation and assist in maintaining personnel doses less than Administrative Control Levels.

Supplemental dosimeters shall be issued to personnel prior to entry into a High or Very High Radiation Area [835.502(a)(2)]. Supplemental dosimeters should also be issued when planned activities could cause an individual to exceed 50 millirem or 10 percent of a facility Administrative Control Level from external radiation in 1 work day, whichever is greater or when required by a Radiological Work Permit. Pocket dosimeters should be selected with the lowest range applicable (typically 0-200 mR) for anticipated personnel exposures.

Supplemental dosimeters should be worn simultaneously with the primary dosimeter and located on the chest area, on or between the waist and the neck.

Supplemental dosimeters should be read periodically while in use and should not be allowed to exceed 75 percent of full scale.

Work authorized by written authorization should be stopped when supplemental dosimeter readings indicate total exposure or rate of exposure substantially greater than planned. The Radiological Control Organization should be consulted prior to continuation of work.

The energy dependence of supplemental dosimeters, particularly to low-energy beta radiation, should be considered in determining their applicability. For example, the SRPD (shown in figure 5) has a thick case that effectively shields most betas.

Use of electronic dosimeters is encouraged for entry into High Radiation Areas or when planned doses greater than 0.1 rem (0.001 sievert) in 1 work day are expected.

An electronic dosimeter provides an early warning of elevated exposure through the use of alarm set points at specified dose rates or integrated doses.

When the dose results from the pocket or electronic dosimeters differ by more than 50 percent from the primary dosimeter result and the primary dosimeter result is greater than 0.1 rem (0.001 sievert), an investigation should be initiated to explain the difference.

2.04.12 Determine the principle of operation of self-reading dosimetry (SRD) used at your site.

SITE SELF-READING DOSIMETERS

(Insert site specific material here)

Self Reading Pocket Dosimeters (SRPD)

The direct reading pocket dosimeter consists of an ionization chamber sensitive to a desired radiation; a quartz fiber electrometer to measure the charge; and a microscope to read the fiber image off a scale (reticule). (See figure 5)

The electrometer embodies two electrodes, one of which is a moveable quartz fiber and the other a metal frame. When the electrometer is charged to a predetermined voltage, the electrodes assume a calibrated separation.

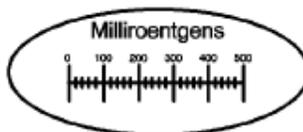
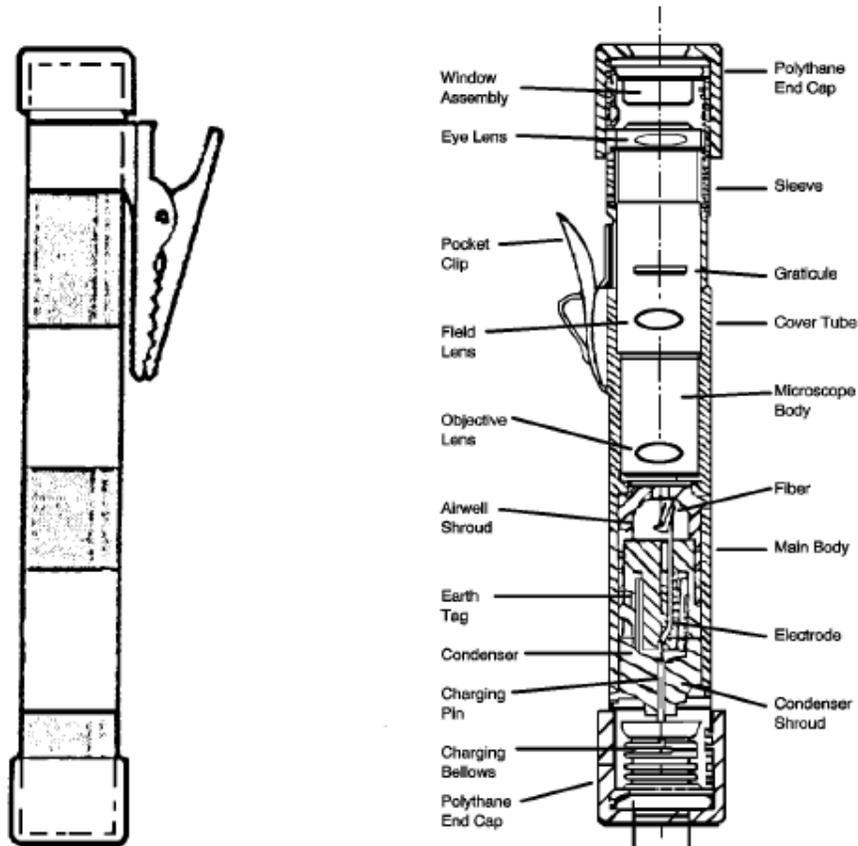


Figure 5 - SRPD

As the dosimeter is exposed to radiation, ionization occurs in the surrounding chamber decreasing the charge on the electrode in proportion to the exposure. The deflection of the moveable quartz fiber electrode is projected by a light source through an objective lens to a calibrated scale and read through a microscope eyepiece. (See Figure 6)

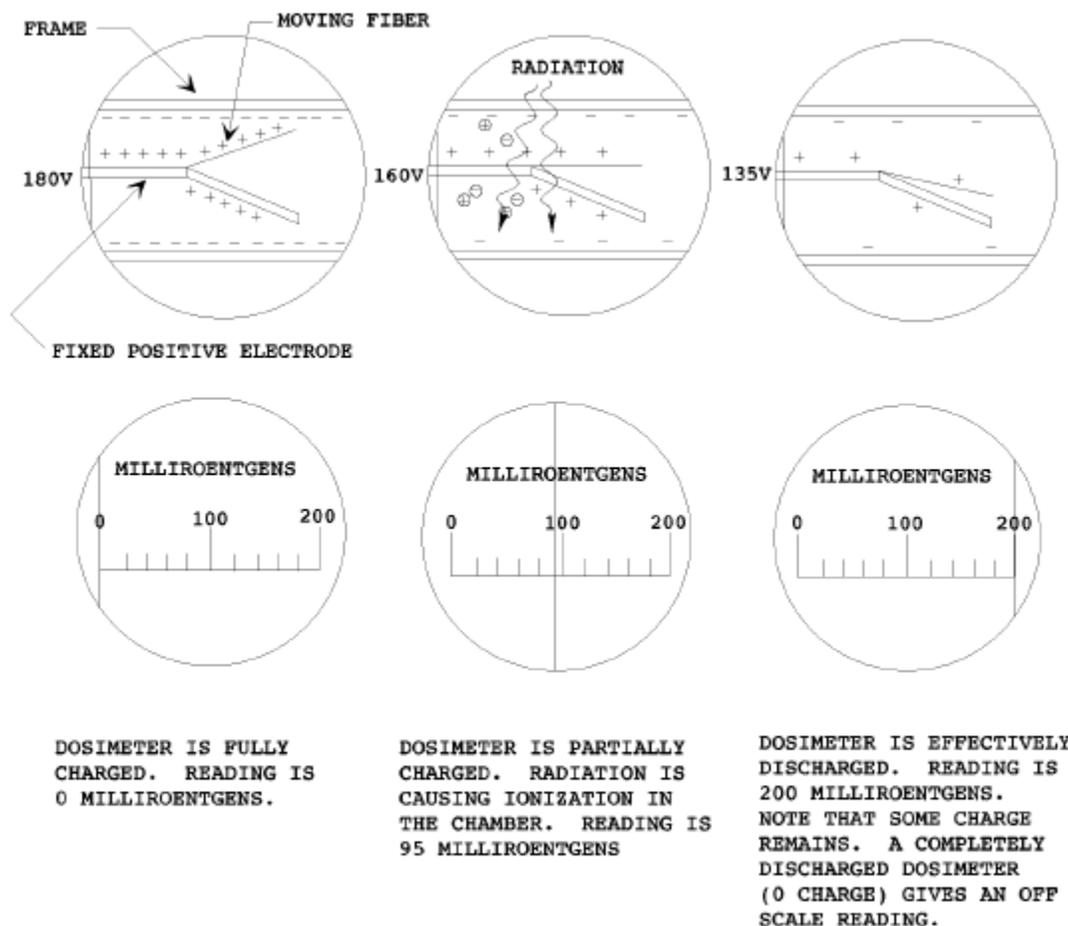


Figure 6 - SRPD Reading

Illumination for the optical system is obtained by pointing the dosimeter at any convenient light source. Light passes through the clear glass bottom seal to illuminate the scale.

The bottom is sealed by a bellows containing an insulated charging pin. When charging, the charging pin moves up to contact the electrometer closing the circuit. Sufficient voltage is applied to recharge the system. The entire dosimeter system is hermetically sealed in a protective barrel.

SITE ALARMING DOSIMETRY

2.04.13	<i>Determine the principle of operation, and guidelines for use, for the alarming dosimeters used at your site.</i>
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(Insert site specific material here)

INTERNAL DOSIMETRY REQUIREMENTS

Per 10 CFR 835: for the purpose of monitoring individual exposures to internal radiation, internal dose evaluation programs (including routine bioassay programs) shall be conducted for:

1. General employees who, under typical conditions, are likely to receive 0.1 rem (0.001 sievert) or more committed effective dose from all occupational radionuclide intakes in a year;
2. Declared pregnant workers likely to receive an intake resulting in an equivalent dose to the embryo/fetus in excess of 10 percent of the limit (or 0.05 rem [0.0005 sievert]);
3. Occupationally exposed minors who are likely to receive a committed effective dose in excess of 50 percent of the applicable limit (or 0.05 rem [0.0005 sievert]) from all radionuclide intakes in a year;
4. Members of the public entering a controlled area likely to receive a committed effective dose in excess of 50 percent of the limit (or 0.05 rem [0.0005 sievert]) from all radionuclide intakes in a year.

The estimation of internal dose should be based on bioassay data rather than air concentration values unless bioassay data are unavailable, inadequate, or internal dose estimates based on air concentration values are demonstrated to be as or more accurate.

Personnel should participate in follow-up bioassay monitoring when their routine bioassay results indicate an intake in the current year with a committed effective dose of 0.1 rem (0.001 sievert) or more.

Personnel whose routine duties may involve exposure to surface or airborne contamination or to radionuclides readily absorbed through the skin, such as tritium, should be considered for participation in the bioassay program.

Personnel should submit bioassay samples, such as urine or fecal samples, and participate in bioassay monitoring, such as whole body or lung counting, at the frequency required by the bioassay program.

Personnel should be notified promptly of positive bioassay results and the results of dose assessments and subsequent refinements. Dose assessment results should be provided in terms of rem or mrem.

BIOASSAY ASSESSMENT METHODS

Today's technology has not produced a device that allows accurate determination of internal exposure following the entry of radioactive materials into the body.

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.

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: *in vivo* and *in vitro*. *In vivo* bioassay involves counting the living tissue, as described below. *In vitro* involves counting an excreted sample, such as urine.

Bioassay programs are designed to fulfill two needs:

- 1) Evaluate effectiveness of contamination control practices
 - Routine bioassay programs utilize submission and analysis of samples from workers in facilities where the likelihood of intake exists
 - Primarily limited to urinalysis due to ease of sample collection
 - Also includes initial, routine, and termination whole body counts
- 2) Evaluate potential consequences of accidental inhalation or ingestion of large quantities of radioactive materials
 - Can involve all types of bioassay measurements with collection and analysis of nasal, urine, and fecal samples.
 - Whole body counts provide immediate indications for given radionuclides if individual(s) involved are free of external contamination.

Quantification of materials actually in the body can be affected by the availability of measurements taken early after the incident. The elimination rate of some materials from the body falls off as the concentration in the body falls off, or with time. Accurate quantification of initial quantities, present, thus accurate dose assessment, can be dependent on availability of early data.

Identification of the proper bioassay technique to use is aided by a knowledge of the types of contamination present in a particular work area. For example, if you know that the contamination in a facility typically includes radionuclides that cannot be detected with in vivo measurements, then it would be obvious that collection and measurement of urine or other samples is necessary.

If the presence of gamma emitting nuclides is identified, consider the possibility of the presence of materials that do not decay with gamma emission. Periodic radionuclide assessment of contamination in facilities will provide information on relative radionuclide concentrations. Caution must be exercised in using information of this nature. Cycles of contamination should be used as an indicator only. Remember, fresh coolant does not have the same isotopic makeup of coolant that has decayed.

Contamination control measures cannot be too stringent during collection, handling, and analysis of bioassay samples. Cross-contamination can cause erroneous assumptions and inaccurate dose assessments. If procedural guidance is not sufficient to determine required actions, consult supervision.

In Vivo Measurements

In vivo techniques consist of direct measurements of gamma or X-radiation emanating from the body. This method is very useful for any radionuclide which emits (or has daughters which emit) photons of sufficient energy to escape the body. The photon flux density must be large enough for measurement in a reasonable time period, even though the quantity of material in the organ is very small.

This method is possible only for those radionuclides emitting penetrating radiation, e.g., Co-60 and Cs-137 or bremsstrahlung, e.g., P-32 and Sr-90. Many radionuclides, Na-22, Fe-59, Co-60, Zn-65, Rb-86, Sr-85, Te-132, I-131, Cs-137, Ba-140, Ce-144, Au-198, U-235, Np-239, and Am-241 emit electromagnetic radiation of sufficient energy to be measured by external counting. If the counter has been calibrated previously, one may rapidly determine the identity and amount of any of these radionuclides. Such measurements are more acceptable to the subject than the provision of samples of excreta, although they do require him to be absent from work during the period of measurement. Direct counting of the individual without preparation beforehand (changing into clean clothes and external decontamination) may give misleading results, since this method measures all gamma emitting radionuclides in or on a subject; therefore, sensitive counts (lung) should be done immediately after the subject washes and changes into clean clothing. Radon

daughters that cling to body hair due to their electrostatic charge are the chief source of bad lung counts. When this method errs, it usually does so by being too high, so that a negative result is likely to be a reliable indication that there is no internal contamination with gamma emitters.

In external counting, the requirement for sensitivity and energy discrimination determines the complexity of the measuring equipment. Estimations of very small quantities require elaborate shielding of both the sensing element and the subject, sensitive detectors, and the best discrimination between gamma ray energies. However, a single moderately large, well-shielded sodium iodide crystal coupled with a multichannel analyzer can usually meet the need. This system in conjunction with a shielded chair or moving bed, is capable of determining:

- I-131 in the thyroid gland.
- Insoluble radionuclides in the chest.
- Insoluble radionuclides in the intestine.
- Insoluble radionuclides in wounds.

These need not emit highly penetrating radiation, since much of the material may be on or near the surface, i.e., for wounds.

Because large sodium iodide crystals do not have good collimation capabilities, it is usually not possible to measure specific organ contents directly. In some cases, solid state detector

(GeLi) can be used for specific organ determination. However, the decreased sensitivity of this method limits the usefulness of these measurements. Small sodium iodide detectors are used for determining thyroid dose.

2.04.14 <i>List the types of bioassay monitoring methods at your site.</i>
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Site In Vivo Methods

(Insert site specific material here)

Advantages of In Vivo Measurements

- No sample required
- Results obtained quickly
- Some equipment design allows field use
- Time and manpower requirements minimized.

Disadvantages of In Vivo Measurements

- Limited to detection and measurement of gamma emitters
- Individual must be free of external contamination
- Long count times for identification
- Effects of background
- Complex calibration procedure and calibration equipment
- Expense
- Quantification error due to differences in tissue structure from one person to another as compared to calibration phantom.

In Vitro Measurements

The amount of material present in the body is estimated using the amount of materials present in excretions or secretions from the body. Samples could include urine, feces, blood, sputum, saliva, hair, and nasal discharges. Calculation requires knowledge and use of metabolic models which allow sample activity to be related to activity present in the body.

Resulting dose calculations to quantify committed and effective doses are estimates. 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. Another contributing factor is the difference in metabolism from one individual to another.

Urinalysis

Indicates effectively that soluble radioactive material has been deposited in the blood for transport to various organs. A fraction of the material is normally removed from the blood by

the kidneys and excreted. Later, material absorbed by various organs may be released to the blood through biological exchange processes, and then may be excreted in the urine.

Certain compounds are determined to be insoluble because they are avidly retained in the lung. However, they also eventually appear in the urine. Particles are removed to the pharynx by the ciliary-mucus transport mechanism where they are swallowed, dissipated and partially absorbed in the gastrointestinal tract for transport to the blood. Other particles are removed by transport to the lymphatic system for subsequent release to the blood. Other particles slowly enter into a physical or chemical state which allows direct transport from the pulmonary region of the lung to the blood. All three cases lead to urinary excretion of the material.

Taking samples of urine involves two special difficulties. One is the possibility of contamination if the sample is taken at work. The other is the problem of collecting a sample from which can be calculated the total excretion of radionuclide per unit time, usually per day. It is ordinarily not convenient to collect a full 24-hr sample of urine, so it is frequently necessary to estimate the fraction this is of the relatively constant daily urine excretion.

One of the advantages of measuring the radionuclide content of urine is that if a radionuclide is found in a carefully collected sample of urine, there can be no doubt that it was in extracellular body fluids. Furthermore, under the most favorable conditions, the amount of daily urinary excretion of radionuclide may be used directly to calculate total body content. One of the simplest examples of practical importance is tritium oxide which is present in the same concentration in urine as in extracellular fluids of the body.

Almost all employees are willing to provide a limited number of urine samples; however, prolonged urine sampling involving samples taken both at home and at work will often meet with increasing employee resistance.

Fecal Analysis

An appreciable fraction of the particles entering the gastrointestinal tract may not be absorbed; these appear in the feces within twenty-four hours. Thus, fecal analysis is an excellent and relatively rapid indicator that an exposure has occurred. Fecal analysis is particularly useful for inhaled, insoluble materials that do not appear in the urine for weeks. For many highly insoluble materials, particles remaining in the pulmonary system continue to reach the mucus blanket, although at a greatly reduced rate. These particles are then transported by ciliary action to the gastrointestinal tract. Thus, fecal analysis can also contribute to the estimate of the lung burden.

Two drawbacks to fecal analysis are: (1) there is considerable employee resistance to provide fecal samples and (2) there is very little correlation between fecal content and organ depositions. Thus, fecal analysis is primarily a qualitative method used only for detecting the intake of insoluble materials and providing indication of clearance of such materials from the lungs. Fecal sampling is normally done immediately following an incident because correlation is best when intake times are known.

Sputum

When obtainable, sputum may contain insoluble material initially deposited in the lung and later eliminated by ciliary action. However, clearance time for sputum is very rapid and samples must be taken immediately after an incident.

Saliva

May be analyzed to detect internal contamination, but the only practical case in which saliva can be used to estimate body content is that of tritium oxide, for which urine is the usual method.

Nasal Discharge

The presence of radionuclides in nasal discharge and nasal swabs generally gives an indication of the deposition of the coarsest inhaled particles in the nose. Measurement of the amounts present cannot always be used for quantitative estimation of the amount in the body, but it can be useful in detecting significant exposures and identifying the radionuclide involved in an accident.

2.04.14 List the types of bioassay monitoring methods at your site.

Site In Vitro Methods

(Insert site specific material here)

Advantages of In Vitro Measurements

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

Disadvantages of In Vitro Measurements

- Requires sample submission and analysis
- Time and manpower requirements

BIOASSAY SCHEDULING PROGRAM

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

Baseline/Routine/Exit Evaluations

(Insert site specific material here)

Special Evaluations

(Insert site specific material here)

Investigation Levels

(Insert site specific material here)

Medical Uses

(Insert site specific material here)

SUMMARY

The method of operation of dosimeters is a vital knowledge for RCT. RC personnel are the first line of defense against abuse of these instruments and must ensure the proper wearing and use of them.

Internal exposure involves a source (contaminant) inside the body. It is more difficult to measure; sophisticated whole body counters or indirect measurements of excreta samples are required to obtain an estimate. The exposure from the contaminant does not stop when the person leaves the radiation field and the contaminant continues to irradiate tissue all day and all night. If necessary, medical treatment is required to enhance the removal of the source material from the body. Alpha radiation poses the biggest problem.

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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.

INTRODUCTION

Contamination control is probably one of the most difficult and challenging tasks the Radiological Control Technician will encounter. To have a successful contamination control program, the radiological control staff must have considerable foresight, initiative, and experience.

References:

1. DOE Radiological Control Standard, Articles 325, 337 and 338 (2008).
2. "The Health Physics and Radiological Health Handbook," Shleien; 1992.

TYPES OF CONTAMINATION

2.05.01 Define the terms "removable and fixed surface contamination," state the difference between them and list common methods used to measure each.

Contamination is simply defined as radioactive material in an unwanted location, e.g., personnel, work areas, etc. Two types of contamination are possible, fixed and removable. Fixed contamination is radioactive surface contamination that is not easily transferred to other personnel or equipment through normal contact. Removable contamination is radioactive surface contamination that is easily transferred to other personnel or equipment through normal contact.

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 cm² of the surface of interest using moderate pressure. A common sampling practice used to ensure a 100 cm² sample is to wipe a 16 square inch "S" shape on the surface (i.e., 4 inches by 4 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.

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. When non-removable levels are to be recorded, the removable level must be subtracted from the total.

Appendix D to 10 CFR 835 lists contamination levels in units of dpm/100 cm². 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 dpm/100 cm².

Footnote 4 to Appendix D states that when "removable contamination on objects of surface area less than 100 cm² 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 cm², 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 cm²/50 cm²) to get a result in units of dpm/100 cm². A similar approach may be used for fixed contamination monitoring of objects with surface area less than 100 cm². However, care must be taken in monitoring very small objects and the sensitivity of the monitoring protocol should be evaluated.

ASSESSING CONTAMINATION HAZARDS

2.05.02 *State the components of a radiological monitoring program for contamination control and common methods used to accomplish them.*

In order to acquire the radiological information necessary for contamination control, there are several components to a radiological monitoring program. These are:

- Constant monitoring
- Area and equipment surveys
- External personnel surveys
- Personnel internal monitoring and bioassay

Constant Monitoring

There are various types of constant monitoring instruments throughout the facilities to warn personnel of radiation and contamination hazards. Some instruments are permanently installed, and some instruments are portable to allow movement from place to place as deemed appropriate by the radiological control staff.

Continuous air monitor (CAM). These instruments continuously sample the air for radioactive contamination in specific locations. The air being sampled is either drawn through a moving particulate filter which is then monitored by a detector system or through an internal detector to directly identify radioactive materials present. A CAM can give both a visual and audible alarm to warn personnel of the presence of airborne contamination.

Process monitoring systems. Process monitoring 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.

Area and Equipment Surveys

Area and equipment surveys are conducted routinely throughout the facilities to locate sources of radiation and contamination and to detect potential changes in radiological conditions. Pre-job surveys are performed prior to work in radiological areas in order to evaluate the hazards and determine work limitations and physical safeguards.

Direct instrument surveys. Various types of portable survey instrumentation are used to measure the presence of radioactive contamination on a floor or surface. This is the only method available to detect "fixed" surface contamination. It must

be remembered, however, that this method will detect removable as well as "fixed" surface contamination activity. As a result, a direct survey must be combined with a "smear" survey to determine if the surface contamination present is removable or fixed.

Smear surveys. 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. Contamination levels are specified in units of dpm/100 cm² after applying applicable instrument correction factors. For objects less than 100 cm², the units are reported as dpm/object area. Disk smears are small so they are usually used in an area of suspected contamination. Properly applied experience will dictate to the surveyor where contamination is most likely to occur and hence those areas that should be surveyed with disk smears. Disk smears are required if contamination levels are to be quantified.

Many routine contamination surveys are taken in areas not suspected to be contaminated with a chemically treated cloth called a masslinn (paper towel, atomic swipe, etc). The cloth is lightly pushed over an area and scanned with an appropriate detector to detect the presence of contamination. If contamination is detected, a more thorough disk smear survey should be performed. These large area wipes are used only as an indication of removable surface contamination.

External Personnel Surveys

Personnel surveys are either performed by the individual (self-monitoring) using hand-held or automated instruments or by a radiological control technician. Self-monitoring is typically performed upon exiting a contaminated area at established boundary points. Personnel 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 feasible (remote location) or not allowed. The types of hand-held or automated instruments used for self-monitoring are generically described below.

Personnel monitors. Portable instruments (friskers) with sensitive hand held detectors are used by personnel to identify contamination on themselves whenever contamination is suspected. These monitors are used whenever exiting contaminated areas, Radiological Buffer Areas, and in some cases Radiological Control Areas (RCA). Geiger-Mueller (GM) detectors are most often used for beta-gamma monitoring and scintillation detectors for alpha monitoring.

Personnel Contamination Monitors (PCM). The PCM provides personnel with an external whole body monitoring system. The 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 present in the area and the personnel contamination limit of concern. These automated systems

typically provide a more reliable method of locating personnel contamination over hand-held instruments.

Hand and Foot Monitors. Hand and foot monitors with detachable hand-held detectors provide another alternative to using hand-held instruments (friskers). These devices can monitor the hands and feet during a period of a few seconds, again, dependent upon background radiation levels present in the area and the personnel contamination limit of concern. After the hands and feet have been monitored, the detachable hand held detectors, which are typically of a larger detector size, can be used to monitor the remainder of the body in a shorter time period than most friskers.

Portal monitors. The portal monitor is a "door frame" type device which provides a final monitoring point to ensure contamination is not spread outside the facility to other facilities or the general public. These types of monitors are typically used only for beta-gamma monitoring.

Personnel surveys. Personnel surveys are performed whenever contamination of the body or clothing is suspected, or as required for exit monitoring, e.g., when friskers or automated monitoring instruments are not available.

The whole body should be surveyed with special attention to areas which are more likely to become contaminated. Contamination of the feet (shoes) would indicate removable surface contamination on the floor just traversed. The hands are extremely prone to becoming contaminated when working directly with radioactive materials. Upon completion of work or prior to leaving the area for glovebox, laboratory fume hood, sample station, or localized benchtop operations, a minimum survey of hands, arms, and front portions of the body must be performed.

Other body areas which are prone to contamination are the buttocks, knees, and elbows and head.

The nose and mouth should be surveyed upon discovery of any level of facial skin contamination, or if airborne contamination was detected in the workplace, since contamination in this area might indicate the need for bioassay sampling. The nose can be swabbed with Q-tips and the swab counted in a smear counter to determine a potential deposition. Contamination of the nose or mouth may indicate airborne contamination.

All open wounds must be monitored since contaminants can be readily absorbed into the body.

In addition to these specific body areas, the surveyor should pay special attention to any area of the body and/or clothing which he or she suspects might be contaminated.

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.

Personnel Internal Monitoring

A routine program of internal contamination monitoring is conducted as a final check on contamination control procedures. This program consists of external whole/partial body counting and/or urinalysis.

In-vivo Bioassay: The individual is placed inside a array of very sensitive detectors to measure the activity and energies of gamma ray emissions from inside the body. This information can be used to determine the amount and identify the type of nuclides present. Examples include whole body, lung, or scanning bed counters.

In-vitro Bioassay: Urine or feces samples are collected from an individual to determine the type and activity of the nuclides present in bodily waste. This information is used to approximate the amount of nuclides present in the body by their calculated rate of elimination. This method can be used to assess the presence of non-gamma emitting nuclides.

BASIC GOAL OF CONTAMINATION CONTROL

2.05.03 *State the basic goal of a contamination control program and list actions that contribute to its success.*

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.

In some situations, this is not always possible due to:

- Economical conditions: Cost of time and labor to decontaminate a location(s) out-weighs the hazards of the contamination present.

- Radiological conditions: Radiation dose rates or other radiological conditions present hazards which far exceed the benefits of decontamination.
- Operating conditions: Some areas, e.g., hot cells, will be contaminated due to normal operations.

Other means of control must be initiated when decontamination is not possible. Engineering control (ventilation and containment), administrative procedures (RWPs), and personnel protective equipment are alternatives for the control of contamination. In Fixed Contamination Areas the contamination may be covered by paint, floor tiles, etc. when decontamination is not possible.

"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. A sound preventive and corrective maintenance program can prevent many radioactive material releases. All material taken into or out of contaminated areas must be controlled. RCTs should always be alert for potential violations to the basic principles of contamination control.

- Use of improper contamination control methods
- Bad work practices
- Basic rule or procedure violations
- Radioactive material releases or liquid spills

CONTAMINATION CONTROL MEASURES

Controlling the spread of contamination is probably the most difficult and challenging task the Radiological Control Technician will encounter. To have a successful contamination control program, the radiological control staff must have considerable foresight, initiative, and experience. The radiological control staff will assist line management with the basic principles of contamination control.

2.05.04 *State the basic principles of contamination control and list examples of implementation methods.*

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

Access/Administrative Controls

Once contamination has been located and quantified and radiological areas have been determined, access control to these areas must be adequately established. Two basic access control points, primary and secondary, are used in contamination control.

The primary access control point in a facility is the entry and exit portal between the clean area and the radiologically controlled area or Radiological Buffer Area. 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.

The secondary access control points (perhaps the most important) are set up within the Radiological Buffer Areas (RBAs) to control access between surface contaminated areas and non-contaminated areas. Yellow and magenta rope, chain, tape or similar barriers are used to identify the boundaries and provide a recognizable visual barrier to personnel. In areas of ongoing work activities, special requirements will always be established for entry and exit through these access control points. When the radiological conditions are severe, the access control point may be continuously manned by a Radiological Control Technician. It is not expected that Radiological Buffer Areas will be established around inactive or secured Contamination Areas.

Step-off pads (SOPs) identify the entry and exit points to contaminated areas when possible. The use of SOPs creates a sharp line of distinction between the surface contamination area and the clean areas. Proper procedures must be established and observed for crossing the SOP to prevent the spread of contamination. All tools and/or equipment used in a surface contamination area which are unmonitored should be placed in clean plastic bags or securely wrapped in plastic before being removed from the area. All personnel and materials exiting the area should be monitored to ensure they are free of contamination.

Radiological Buffer Areas should also be established in areas where there is a need to limit exposure to external radiation, such as Radiation, High Radiation, and Very High Radiation Areas. The boundary should be established to limit radiation dose to general employees to less than 100 mrem per year. RBAs need not be posted for external exposure control if other posted boundaries provide equivalent employee protection.

Other administrative controls used for contamination control include the use of Radiological Work Permits, routine workplace surveys that are performed in order to detect trends in the potential buildup of workplace contamination, and

review of operational and maintenance procedures to ensure radiological requirements are incorporated in the daily conduct of operations.

ENGINEERING CONTROLS

2.05.05 *List and describe the possible engineering control methods used for contamination control.*

Ventilation. The design of permanent or temporary ventilation systems needs to be such that air flow is from clean areas to RCAs, to areas of moderate contamination, to areas of high contamination, and finally to an exhaust system capable of removing any contamination from the air. Slight negative pressure is typically maintained in buildings/rooms where potential contamination exists. As necessary, high efficiency particulate air (HEPA) filters are used to remove radioactive particles from the air.

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. A portable ventilation exhaust system (such as HEPAs) may be used to control air flow in the work area and remove airborne contamination. 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. Drums or other approved containers are also utilized.

Bagging. The most widely used method of containment is bagging or wrapping. Contaminated tools or equipment are placed in plastic bags, or securely wrapped in plastic, before being moved outside a contaminated area. When possible, wrapping tools or equipment prior to entry can help control contamination during use inside the contaminated area.

Design and Control. Design of facilities should be such that efficiency of maintenance, operations, and decontamination is maximized. Components should be selected that minimize the buildup of radioactivity. Support facilities are to be included that provides for donning and doffing of protective clothing and for personnel monitoring. Personnel traffic should be routed away from contaminated areas.

PERSONNEL PROTECTIVE MEASURES

2.05.06 *State the purpose of using protective clothing in contamination areas.*

If engineering control methods are not adequate, then personnel protective measures, such as protective clothing and respiratory equipment, will be used. The purpose of protective clothing is to keep contamination off the skin and clothing of the workers. Protective clothing allows personnel to work inside a contaminated area with removable contamination and to exit the area without spreading contamination to uncontrolled areas. The 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.

All personnel entering contaminated areas with removable contamination will be required to wear certain items of protective clothing. The types of clothing required will vary depending upon the contamination levels and the nature of the work to be performed. Some additional factors for the selection of protective clothing include the type and form of contamination; potential for increased levels of contamination, area of the body at risk, and competing hazards, i.e., heat stress, asbestos, etc.

Some type of respiratory protective equipment will be required for work in areas where very high contamination levels exist or airborne contamination is present.

Decontamination

Line management is responsible for ensuring prompt decontamination, where practical, of facilities, tools, material, and equipment 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. Only items that are extremely contaminated with risks during decontamination that out-weighs the benefit to be gained for reuse should be considered for disposal.

Preventive Methods

The following are practical methods used for the prevention/control of contamination:

- Identify and repair leaks before they become a serious problem.
- Establish adequate work controls before starting jobs.
- While conducting pre-job briefs, discuss measures that will help reduce or prevent contamination spread.
- Change out gloves or protective gear as necessary to prevent cross-contamination of equipment.
- Pre-stage areas to prevent contamination spread from work activities.

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

BASIS FOR ESTABLISHING PROTECTIVE CLOTHING REQUIREMENTS

In order to prevent radioactive contamination from getting on or into the body, protective clothing requirements must be established where the potential exists.

<i>2.05.07 List the basic factors which determine protective clothing requirements for personnel protection.</i>
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There are several basic factors which determine the type and extent of protective clothing required:

- type and form of contamination
- levels of contamination
- type of work being performed

Some additional factors to consider include the potential for increased levels of contamination, the area of the body at risk, and competing hazards, i.e., heat stress, asbestos, etc. 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 discussion of the controls/clothing types for specific areas of the body follows.

Whole body protection

A lab coat provides protection from low levels of contamination and is only applicable when the potential for upper body contact with contaminated surfaces is very low. In general, lab coats are 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, or during benchtop, laboratory fume hood, sample station, and glovebox operations.

Coveralls provide protection from low to moderate levels of DRY contamination protection. Protection is low when body contact with contaminated surfaces is prolonged (since contamination can be ground into or through the cloth) and when the surface is wet. The degree of protection can be increased by use of more than one pair at a time to protect the body. Cloth coveralls are permeable, and so are not effective against radionuclides with high permeability properties (gases, tritium, etc.).

Plastics coveralls provide protection from high levels of dry contamination and wet contamination. They provide limited protection from tritium and other highly permeating radionuclides (which may be transported through coveralls to the skin surface).

Disposable coveralls, e.g., tyvek suits, provides moderate protection from radioactive contamination and are used for work involving mixed hazards, i.e., asbestos, PCBs, etc., where reuse is not desirable. Disposable coveralls can be fairly easily torn.

It should be noted that at a minimum, outer personal clothing should not be worn under protective clothing for entry into High Contamination Areas or during work conditions requiring a double set of protective clothing. Sites may choose to be more restrictive as necessary to minimize potential skin/clothing contamination.

Hand protection

Surgical gloves are a minimal requirement normally used in only light contamination work areas which require a high degree of dexterity. Surgical gloves are fairly easily torn or punctured.

Rubber gloves are lightweight and provide a good gripping surface. They are normally used in moderate to heavy contamination locations. Rubber gloves have greater puncture, abrasion and solvent resistance, but afford a lower degree of dexterity than surgical gloves.

Neoprene gloves are synthetic rubber gloves mounted to various containment devices to allow access by the wearer into the device. They are used to provide protection for the wearer when working inside a containment device in which highly contaminated materials are present. They are usually of arm length attached to dry boxes, glove boxes and bags, or other cabinets and provide a gas tight seal to the structure. Gloves are normally taped to the sleeve of the lab coat, coveralls, plastic suit, etc. and are tabbed to permit easy removal.

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

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.

Foot protection

Booties are used to protect the lower leg area below the coveralls from contamination. Different constructions used are plastic and cloth (sometimes called cloth shoe covers).

Shoe covers are worn over booties to provide a second layer of protection and provide traction to wearer. They are normally constructed of plastic or rubber, and may be taped to the pant legs of the coveralls or plastic suit depending on the level of contamination and type of job.

Respiratory protection

Full face masks are 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.

Supplied air systems may prevent inhalation of particulate and gaseous nuclides by the wearer in a non-life threatening atmosphere.

A self contained breathing apparatus (SCBA) is 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.

Medical approval, training, and fit testing are required prior to respiratory protection use. Systems should be in place to verify these criteria in the field. To ensure proper use of a respirator prior to entering areas requiring its use, the wearer should be clean shaven in the area of fit and he/she should perform fit checks of their respirators to ensure a proper seal.

FACILITY PROTECTIVE CLOTHING REQUIREMENTS

(Insert facility specific material here)

SUMMARY

All reasonable efforts must be made to control contamination in order to provide protection for workers on site and the general public from the hazards presented by radioactive material. This lesson covered the phases of a contamination monitoring program, and the goal, principles, and methods used to support the contamination control program.

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.
 - a. Filtration
 - b. Volumetric
 - c. Impaction/impingement
 - d. Adsorption
 - e. Condensation/dehumidification
 - f. 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:
 - 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
 - e. 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.

INTRODUCTION

Inhalation of radioactive particles is the largest cause of internal dose. Airborne radioactivity measurements are necessary to ensure that the control measures are effective and continue to be effective. Regulations govern the allowable dose to an individual. The total effective dose is determined by combining the external and internal effective dose values. Typically, airborne radioactivity levels are maintained well below allowable levels to keep the total dose small.

References:

1. "Introduction to Health Physics"; Cember, Herman; 4nd ed.; McGraw-Hill Medical; 2008.
2. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5th 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".

INTRODUCTORY KNOWLEDGE

In order to understand the "allowable effective dose values", you must have a basic understanding of the Annual Limit on Intake (ALI), and Derived Air Concentration (DAC). (Refer to RCT lesson 1.12 sections 3 to 8).

Annual Limit on Intake (ALI) - The quantity of a single radionuclide which, if inhaled or ingested in one year, would irradiate a person, represented by reference man (ICRP Publication 23), to the limiting value for control of occupational exposure.

Derived Air Concentration (DAC) - The concentration of a radionuclide in air that, if breathed over a period of a work year, would result in the ALI for that radionuclide being reached. The DAC is obtained by dividing the ALI by the volume of air breathed by an average worker during a working year (2400 m^3).

The DAC is the average airborne concentration that a radiation worker may be exposed to for 40 hours/week, 50 weeks/year. When continuously exposed to this concentration, the resultant dose is either a committed effective dose of 5 rem or a committed equivalent dose to an organ or tissue of 50 rem (whichever one is more limiting). Since the DAC is a time-average concentration, as the concentration increases, the exposure time must decrease in order to maintain exposure below the ALI. This means that one could be exposed to concentrations significantly above the DAC for short periods of time and still be below the annual limit on intake, or ALI.

Example 2.06-1

The DOE, in 10 CFR 835, has set a DAC for tritium gas of 200 mCi/m^3 , and a DAC for HTO of $20 \text{ } \mu\text{Ci/m}^3$. Notice that the DAC for tritium gas is 10,000 times higher than the DAC for HTO.

HTO	$20 \text{ } \mu\text{Ci/m}^3$
T_2 (gas)	$200,000 \text{ } \mu\text{Ci/m}^3$

Exercise: Calculate the dose a worker would receive if he was exposed to 300 mCi/m^3 of tritium gas for 30 minutes.

Exercise: Calculate the dose a worker would receive if he was exposed to 300 mCi/m^3 of HTO for 30 minutes.

PURPOSE AND OBJECTIVES OF AIRBORNE RADIOACTIVITY SAMPLING

Airborne radioactive contaminants are of concern to the radiological control organization due to the biological effects of the ionizing radiation emitted by those contaminants. The inhalation of radioactive airborne particles is one of the most important routes of entry of radionuclides into the human body. 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 that control the radionuclide biokinetics after deposition in the respiratory tract. Air monitoring is performed to identify and monitor airborne radioactive material in order to control the intake of airborne radioactive material by workers.

Regulations govern the allowable or limiting effective doses to an individual. The total effective dose of an individual is determined by combining the external and internal effective dose values. Typically, airborne radioactivity levels are maintained well below allowable levels to keep the internal effective dose contribution to the total effective dose small. Confirmation that airborne radioactivity levels are maintained low is accomplished by the airborne radioactivity sampling program. 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 air concentration values are demonstrated to be as or more accurate.

It is necessary to be aware that the air monitoring program is only one element of a comprehensive radiation protection program. 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.

2.06.01 State the primary objectives of an air monitoring program.

The primary objectives of an air monitoring program are:

- to measure the concentration of the radioactive contaminant(s) in the air by collection and analysis
- to identify the type and physical characteristics of the radioactive contaminant
- to help evaluate the hazard potential to the worker
- to evaluate the performance of airborne radioactivity control measures

- 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

Allowable concentration values, such as derived air concentrations (DAC) are used as an index of the degree of control needed and achieved. Documented measurements of the airborne radioactivity concentrations are required to demonstrate that satisfactory control is achieved and maintained.

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.

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. Allowable concentration values, such as derived air concentrations (DACs), are used as an index of the degree of control needed and achieved. Documented measurements of the airborne radioactivity concentrations are required to demonstrate that satisfactory control is achieved and maintained.

Air sampling is required where an individual is likely to receive an exposure of 40 or more DAC-hours in a year. Other situations requiring sampling are:

- to establish the need for posting of airborne radioactivity areas and to determine the need for respiratory protection of workers
- to assess unknown hazards during maintenance on systems contaminated with radioactive material or when there is a loss of process controls
- to assist in determining the type and frequency of bioassay measurements needed for a worker
- to provide an estimate of worker exposures for situations where bioassay measurements may not be available or their validity is questionable
- 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
- where respiratory protection devices for protection against airborne radionuclides have been required

- real-time air monitoring shall be performed as necessary to detect and provide warning of airborne radioactivity concentrations that warrant immediate action to terminate inhalation of airborne radioactive material

2.06.02 Describe the three physical states of airborne radioactive contaminants.

THE NATURE OF AIRBORNE RADIOACTIVITY

Airborne radioactive contaminants are generally divided into three categories, based on the physical state of the contaminant.

- Particulates
- Gases
- Vapors

The physical properties of airborne radioactive particles can affect inhalation deposition, their dynamical properties in air, and particle solubility in the lung.

Particulates

Particulate contaminants are solid and liquid particles, ranging upward from molecular sizes (approximately 10^{-3} μm), suspended in the air. Solids may be subdivided into fumes, dusts, and smokes, which are distinguished mainly by their mode of generation. Liquids are subdivided into mists and fogs, depending on the dispersion of the liquid particulates. The term "aerosols" is used to collectively refer to relatively stable suspensions of either solid or liquid particles in a gaseous medium. 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. While this suggests that particulate airborne contaminant sampling should measure particle size, this is not practically accomplished on a routine basis. Certain sampling instruments utilize the characteristics of particle size to separate larger particles from smaller particles (e.g., impactors). This is an important factor in that the size range of particles retained in the respiratory tract is generally 1-10 μm .

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. Dissolution in the lungs allows clearance into the blood and the rest of the systemic circulation. For this reason the various absorption types of radioactive particles are classified with respect to their potential solubility in the lungs. Specifically, 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
- Type F for the relatively soluble particles that dissolve in a matter of days in the lung

Gases

Gases are substances that, under normal conditions of temperature and pressure, exist in the gaseous phase. The retention of the gases in the body from inhalation is poor so radioactive gases are usually treated as an external source of exposure. Radioactive gases typically found are the fission product gases, such as xenon and krypton, and naturally occurring radon. While the gases contribute primarily to external exposure, the particulate daughters to which they decay can contribute to internal exposure.

Vapors

Vapors are considered the gaseous phase of a substance that is normally a solid or liquid under normal conditions of temperature and pressure. Airborne vapor sampling is most commonly done for radioiodine and tritium. The contaminant may be dispersed in vapor form at abnormal conditions of temperature and pressure. 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. Sampling methods for vapors should isolate or measure the contaminant regardless of whether the vapor or particulate form is present.

2.06.03	<i>List the primary considerations to ensure a representative air sample is obtained.</i>
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REPRESENTATIVE AIR SAMPLES

To ensure that the sample is representative of the actual conditions:

- The airborne radioactivity concentration entering the sample line must be representative of the airborne radioactivity concentration in the air near the sampling device.
- 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.

When obtaining an air sample, care must be taken to ensure that the sample obtained is representative of the air around the sampling device. This is particularly important for sample lines that directly sample an air flow, such as a stack or duct monitor. Air flow into sampling lines needs to be balanced with respect to the flow of air around the probe or sample inlet. 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. 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.

2.06.03 List the primary considerations to ensure a representative air sample is obtained.

When the sample line velocity is equal to the system velocity at the sample point, it is called isokinetic sampling.

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.

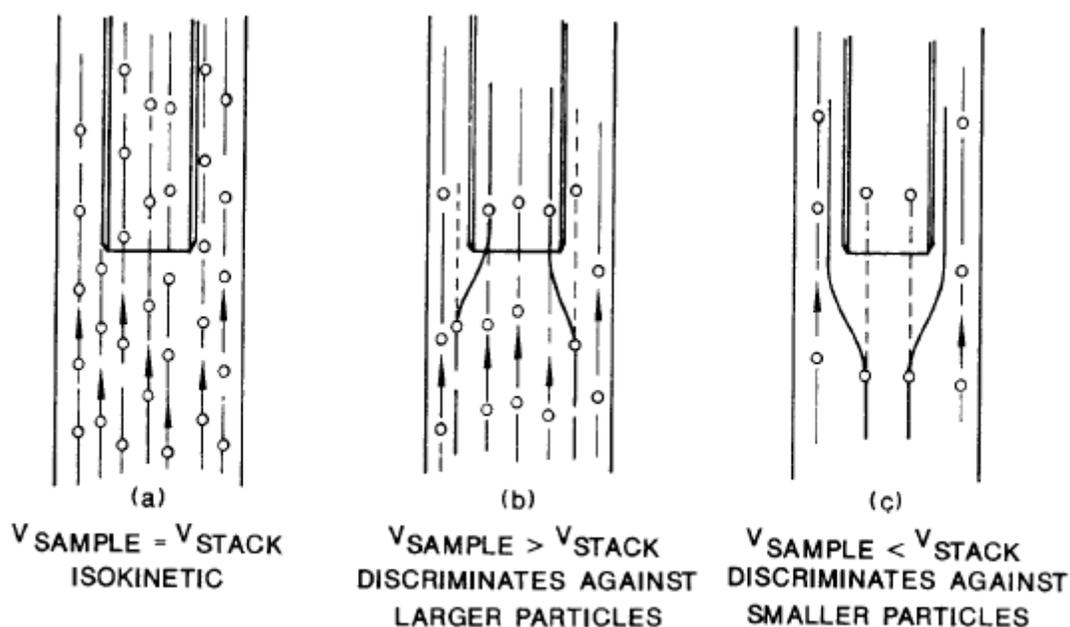


Figure 1 - Isokinetic Sampling

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.

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.

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. Additionally, the sampling line should have no more than one bend and be made of conducting material.

There are other factors to consider for maximizing the efficiency of airborne radioactivity detection. Self-absorption losses, e.g., dust loading, should be minimized. This is especially critical for alpha radiation detection. Air in-leakage between the sample intake and the sample collection medium should be eliminated to the greatest degree possible by instrument design. Finally, 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.

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). Depending on the source of the airborne contaminant, the concentrations within a work area can vary over several orders of magnitude. 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. Obviously, the best sampling method then is to sample the air at the individual's nose and mouth. This sampling method may not always be practical and general work area sampling may be the alternative. 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.

BASIC SAMPLING METHODS

Basically, three types of samples are collected:

1. 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.
2. 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.)

3. 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.

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 exposures and the need for follow-up bioassay measurements.

Source specific air sampling is performed near an actual, or likely, release point in a work area. This is typically used to verify containment or confinement integrity, documenting airborne radioactivity levels, and providing guidance on personnel protective measures (e.g., determining when respiratory protection is required).

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. Portable air sampling equipment is typically used for operations requiring a grab sample. 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.

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

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

- Filtration
- Volumetric
- Impaction/impingement
- Adsorption

- Condensation/ dehumidification
- In-line/flow-through detection

Filtration

Filter samplers employ filtration of the air as the method of concentrating the airborne radioactive particulate (aerosol) contaminants. 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. The filter sampling technique employs an air mover, such as a vacuum pump, to draw air through a removable filter medium at a known flow rate for a known length of time.

- If the flow rate and sample time are known, the total volume collected can be calculated.
- 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.

The filtration medium selected for a sample depends on several factors: the collection efficiency required, the flow resistance of the medium, 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. A wide choice of filters is available.

The most common types are:

- Cellulose-asbestos filters
- Glass fiber 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.

Filter samples are evaluated by direct radiation counting or by radiochemical assay. Filters may be mounted into different types of holders including those with open faces for direct sampling and those with in-line enclosure for sampling through a sampling hose, with sample air flow drawn through a flow meter with a suitable air pump.

Volumetric

Volumetric samplers employ a sample container into which the sample is drawn, by some method, and isolated for analysis. Several methods are employed to draw the sample into the container.

- 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.
- An air mover, such as a vacuum pump, may be employed at the sample location to draw a representative atmospheric sample into the container.
- 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.

This method can be employed for particulates, gases, and vapors.

Impaction/Impingement

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. 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. 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:

- Coating the collection surface with a thin layer of grease or adhesive.
- Immersing the collection surface in a fluid, such as water or alcohol. The liquid is then analyzed after the sample is collected.

Impingers and impactors may utilize several stages or impingement distances to discriminate for or against different particle sizes. 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.

Adsorption

Adsorber sampling devices concentrate the contaminants by causing them to adhere to the surface of the adsorption medium. Adsorption is the adhesion of a

substance to the surface of another substance through chemical bonding. The adsorption medium is granulated or porous to increase the surface area available for trapping of the contaminant. The technique employs an air mover to draw and collect the sample through the adsorption media. Adsorbers, such as activated charcoal, silica gel, and silver zeolite, are commonly used to collect organic vapors and non-reactive gases and vapors. Some uses of each type are:

- Activated charcoal is used primarily for radioiodine sampling, but does trap noble gases, such as xenon, krypton and argon.
- Silica gel is primarily used for tritium oxide vapor sampling.
- Silver zeolite is used for radioiodine sampling when trapped noble gases would interfere with the radioiodine analysis.

Particulates would be "filtered" by the adsorption media and must be filtered out before the adsorption process to prevent interference during the analysis of the media.

Condensation/Dehumidification

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. 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. The collected water is frequently analyzed using a liquid scintillation counter. 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. This technique is normally only applied for sampling tritium oxide vapor (HTO or T₂O).

In-Line/Flow Through Detection

In-line or flow-through samplers employ an air mover to direct the sample air flow through or past the detection device. This method is employed for radionuclides which are difficult to collect or detect by other means. 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. In-line detectors are used to measure gaseous activity after filtration and adsorption have been accomplished. Flow-through detectors are employed for radionuclides, such as tritium, which emit low-energy radiation, that could not otherwise pass through the detector window.

Multi-Purpose Samplers and Monitors

The various sampling methods described above may be combined into one sampler or monitor. 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:

- One vacuum pump supplies the air flow for all the samples.
- All the samples are drawn at the same time to minimize the amount of time spent by the technician drawing samples.

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.

2.06.06	<i>Describe the general considerations for selection of an air monitoring method.</i>
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SELECTION OF THE AIR SAMPLING METHOD

It is critical that the proper air sampling method and equipment be selected because:

- The data obtained must be meaningful and accurate to adequately assign radiological control measures
- 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.

The general considerations for the selection of an air sampling method includes several factors.

- The environmental conditions in the area where the sample is to be obtained. 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. High temperature environments may cause some samplers to overheat if run for long periods of time. Explosive gases may be present which could present an explosion hazard for samplers with electric motors not designed for such environments. Dusty areas could cause excessive sample loading which

will reduce sampler flow rates and potentially overheat the sampler. Corrosive environments may lead to the deterioration of the sampling device.

- The physical characteristics of the area in which the sample is to be obtained. An electrical outlet may not be available or close, and a battery powered sampler would be better suited. Close spaces or passages may preclude the use of movable CAMs or heavy samplers.
- 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.
- The expected concentration level. This will determine the length of sample time and type of sampler required. Low-level concentrations will require large volumes to reduce statistical errors and meet minimum sensitivity levels of the analysis equipment. Large volume samples obtained over a long time period are best obtained by samplers designed to run for long periods. If immediate readout of information is needed, then collection and analysis are done at the same time. If not, then samples may be taken and removed to a central analysis location.
- 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.
- The type of survey required. Specific methods, such as breathing zone samples, routine general area samples, general work area samples, general area trending over time, etc., also determines the type of equipment that is selected.
- Procedural requirements. This may dictate a particular type of sample method and/or sample medium for a given application. Prior to selection, one should check the appropriate procedures and ask supervision and experienced technicians for their input.

2.06.07

State the purpose of the five primary types of airborne radioactivity samplers/monitors:

- 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*
- e. *Installed continuous air monitoring systems.*

PRIMARY TYPES OF AIR SAMPLERS

The five primary types of airborne radioactivity samplers/monitors are:

- Personal air samplers (breathing zone)
- High volume/flow rate air samplers
- Low volume/flow rate air samplers

- Portable continuous air monitors (CAMs)
- Installed continuous air monitoring systems

Personal Air Samplers

Personal air samplers (PAS) provide an estimate of the airborne radioactivity concentration in the air the worker is breathing during the sampling period. 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.

PAS 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 samplers themselves may have on a worker's activities. Some characteristics are:

- 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.
- The sampling line terminates in a filter cassette which contains the filtration medium for the radioactive particulate contaminants.
- The sample filter cassette is attached close to the nose and mouth of the individual.

High Volume/Flow Rate Samplers

High volume/flow rate samplers provide an estimate of the airborne radioactivity concentration at a particular location in a short period of time. Portable high flow rate samplers are used to collect airborne aerosols on a filter paper (filtration) or on a greased planchet (impaction). 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. These samplers do not have installed detectors and the sample must be removed from the sampler and analyzed on separate analysis equipment. The high volume/flow rate samplers may be used to:

- Provide a routine "slice of time" estimate of the general area airborne radioactivity
- Verify boundaries of areas posted for airborne radioactivity
- Monitor the airborne radioactivity related to a specific work activity

High volume samplers typically use flow rates of at least 10 cubic feet per minute (cfm). Although these samplers are noisy and not intended for continuous duty, the shorter sample times allow for greater sensitivity.

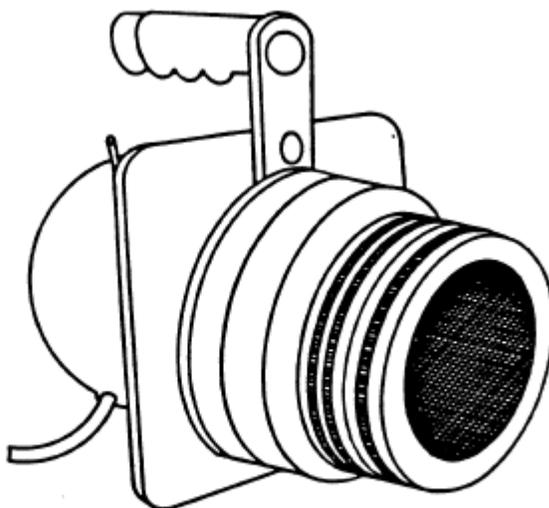


Figure 2 - High Volume Sampler

Low Volume/Flow Rate Samplers

Low volume/flow rate samplers provide an estimate of airborne radioactivity concentrations averaged over a longer period of time at a particular location. 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. Low volume/flow rate samplers may be used to provide average airborne radioactivity estimates over a period of time for:

- Commonly traversed areas that normally have a low probability of airborne radioactivity problems
- Areas not commonly traversed with a higher probability of airborne radioactivity problems

- Backup samples in areas where airborne radioactivity problems are discovered by other means
- Work maintenance activities normally characterized by low airborne radioactivity concentrations.

Low volume samplers generally have flow rates set at approximately 20 lpm, the breathing rate of a worker performing light activity. Although these samplers must run longer for reasonable sensitivity, they are generally quiet and can be used for continuous duty.

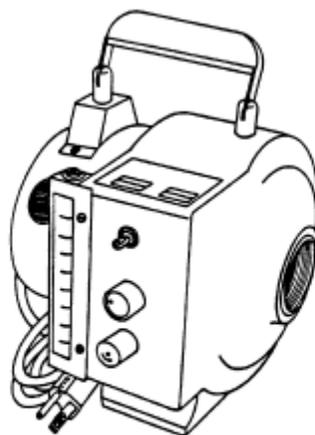


Figure 3
Low Volume Sampler

Portable Continuous Air Monitors

Portable continuous air monitors (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. 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. 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. 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). Portable CAMs can be utilized as:

- Low volume general area samplers
- Monitors with alarm capabilities for areas where airborne radioactivity conditions may quickly degrade
- Trending devices in selected areas
- Devices to locate system leaks, if used with the appropriate length hose or tubing.

Installed Continuous Air Monitors

Installed continuous air monitoring systems (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. 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. 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. Installed CAM applications include:

- Fixed installations capable of sampling several locations through valved sample lines
- Stack monitors
- Duct monitors

2.06.08	List the factors that affect the accuracy of airborne radioactivity measurements.
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Factors affecting the accuracy of airborne radioactivity measurements include:

- Sample is not representative of the atmosphere being sampled
- Sample is not representative of the air being breathed by the worker
- Incorrect or improperly installed sampling media for the selected sampler, causing leak or improper flow rates
- Malfunctioning, miss-operated, or miscalibrated sampling device, causing errors in flow rate measurements

- Accuracy and operation of the timing device, causing errors in the time value
- Accuracy and operation of the flow rate measuring device, causing errors in the flow rate value
- Mishandling of the sample media causing cross-contamination or removal of sample material
- Changes in the collection efficiency of the medium due to sample loading, humidity and other factors
- Improper use or selection of analysis equipment
- Inherent errors in the counting process due to sample geometry, self-absorption, resolving time, backscatter and statistical variations
- Mathematical errors during calculations due to rounding of numbers and simple mistakes
- Incorrect marking of samples and inaccurate recording of data

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.

BASIC AIR SAMPLE CALCULATIONS

Once the air sample is collected and analyzed, calculations must be performed to determine the amount of activity per unit volume.

The specific calculations for particular sampling methods are not covered in this lesson; however, some basics are necessary for each calculation.

The analysis of the sample provides the activity of the sample at the time of the sample analysis. This value may be corrected for decay for the time period between when the sample was taken to when it was analyzed.

- This is especially true for short-lived radionuclides.
- This correction may not be necessary for very long-lived radionuclides.

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.

The basic calculation listed would also include the conversions necessary for the desired units such as dpm/liter to $\mu\text{Ci/cc}$.

$$\text{CONCENTRATION} = \frac{\text{decay corrected activity}}{\text{sample flow rate} \times \text{sample time period}}$$

The calculation would also include correction factors, as necessary, for:

- Interference of other radionuclides, such as radon and thoron daughters
- Collection efficiency
- Counter efficiency
- Self-absorption by the sample media
- Counter background
- Temperature and pressure as applied to flow rate

Many errors are inherent or induced in the sampling analysis process and affect the accuracy of the resulting data. 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. Quality assurance that is applied to all phases of the air monitoring program will minimize many errors.

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.*

(Insert site specific material here)

SUMMARY

This lesson has addressed the primary objectives of an airborne radioactivity monitoring program, the physical states of the airborne contaminants, representative air sampling, the general sampling methods, the factors affecting the accuracy of sample collection and analysis, the primary types of samplers, and the proper selection of the air sampling method.

EXAMPLE SOLUTIONS**2.06-1**

Exercise: Calculate the dose a worker would receive if he was exposed to 300 mCi/m³ of tritium gas for 30 minutes.

Solution: 1 DAC of tritium gas is 200 mCi/m³, so 300 mCi/m³ is 1.5 DAC. 1.5 DAC for 0.5 hours (30 min.) is .75 DAC-hours. One DAC-hr is 2.5 mrem, so .75 DAC-hr is .75 x 2.5, or ~ 1.9 mrem.

Exercise: Calculate the dose a worker would receive if he was exposed to 300 mCi/m³ of HTO for 30 minutes.

Solution: 1 DAC is 20 µCi/m³, so 300 mCi/m³ is 15,000 DAC for 0.5 hours (30 min.) which is 7,500 DAC-hours. One DAC-hr is 2.5 mrem, so 7,500 DAC-hrs is 7,500 x 2.5, or 18,750 mrem, or 18.75 rem.

Key Points: Compare the dose received from HTO to the dose received from exposure to the same concentration of tritium gas in the previous exercise. The dose received for this exposure is 10,000 times worse.

Compare the DACs for tritium and plutonium. For Pu-239 the DAC (Absorption Type M) is given in 10CFR835 as 5E-12 mCi/mL or 2E-1 Bq/m³. List the reasons that inhaling plutonium is more hazardous than tritium.

Confirmation that airborne radioactivity levels are maintained low is accomplished by the airborne radioactivity sampling program. The individual equivalent dose from internal sources is not normally determined from air sampling analysis data, unless bioassay data are unavailable.

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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.

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13. DOE Order 440.1B (2007), Worker Protection Management for DOE (including National Nuclear Security Administration) Federal Employees.
14. ANSI Z88.2 (1992).

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| 2.07.01 | <i>Explain the purpose of respiratory protection standards and regulations.</i> |
| 2.07.02 | <i>Identify the OSHA, ANSI, and DOE respiratory protection program requirements.</i> |
| 2.07.03 | <i>Identify the standards which regulate respiratory protection.</i> |

OSHA AND DOE REQUIREMENTS

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

The Occupational Safety and Health Standard, 29 CFR, Part 1910.134, specifies the minimal acceptable respiratory protection program must contain or address the following:

- Written standard operating procedures and program governing the selection and use of respirators shall be established.
- Respirators shall be selected on the basis of hazards to which the worker is exposed.
- The user shall be instructed and trained in the proper use of respirators and their limitations.
- Respirators shall be regularly cleaned and disinfected. Those issued for the exclusive use of one worker should be cleaned after each day's use, or more often if necessary. Those used by more than one worker shall be thoroughly cleaned and disinfected after each use.
- Respirators shall be stored in a convenient, clean, and sanitary location.
- Respirators used routinely shall be inspected during cleaning. Worn or deteriorated parts shall be replaced. Respirators for emergency use such as self-contained devices shall be thoroughly inspected at least once a month and after each use.
- Appropriate surveillance of worker area conditions and degree of employee exposure or stress shall be maintained.
- There shall be regular inspection and evaluation to determine the continued effectiveness of the program.

- Persons should not be assigned to tasks requiring use of respirators unless it has been determined that they are physically able to perform the work and use the equipment. The health care provider shall determine what health and physical conditions are pertinent. The respirator user's medical status should be reviewed periodically (for instance, annually).
- NIOSH approved or accepted respirators shall be used. The respirator furnished shall provide adequate respiratory protection against the particular hazard for which it is designed in accordance with standards established by competent authorities.

These form the basis for any occupational safety respiratory protection program. ANSI Z88.2-1992 further specifies the minimal acceptable program for industries involved in the use of radioactive material, and addresses the following:

- Individual exposures limited by both inhalation and skin absorption
- Air sampling and bioassays
- Engineering controls as the primary method
- Individuals exposed to greater than the specified DAC or other exposure limits
- Respiratory protection equipment approvals (NIOSH)

If allowance for the use of respiratory protection equipment in estimating radiation exposures is made, then the following must be observed:

- The protection factor must be sufficient to limit the annual internal dose considering the anticipated peak exposure concentration and associated DAC.
- If the exposure is later found to be greater than estimated, the corrected value shall be used, if less than estimated, the corrected value may be used.
- Surveys and bioassays conducted as appropriate to evaluate actual exposures.
- Written procedures for selection, fitting, maintenance, records, issuance and pre-use operability checks of respirators, and supervision and training of personnel using respirators must be established.
- Prior to initial use and annually, determination by a qualified health care professional of a user's physical capability to wear a respirator must be performed.

- A written policy statement on use of engineering controls instead of respirators; routine, non-routine, and emergency use of respirators; and periods of respirator use and relief from respirator use must be issued.
- Each user must be advised that they can leave the work area upon failure of equipment, physical distress or deterioration of operating conditions.
- Equipment is to be used for appropriate environment and special equipment such as visual or communication devices are to be issued when needed.
- Emergency use equipment must be specifically certified as such by NIOSH.

RESPIRATORY PROTECTION EQUIPMENT

- | | |
|---------|--|
| 2.07.04 | <i>Describe the advantages and disadvantages (limitations) of each of the following respirators:</i> |
| b. | <i>Air purifying, Chemical Cartridge and Canister respirators for Gases and Vapors</i> |

Air Purifying, Chemical Cartridge and Canister Respirators for Gases and Vapors

Description:

Vapor and gas-removing respirators use cartridges or canisters containing chemicals (i.e., sorbents) to trap or react with specific vapors and gases and remove them from the air breathed. The basic difference between a cartridge and a canister is the volume of the sorbent.

Limitations:

These respirators do not provide oxygen, so they must NEVER be worn in oxygen deficient atmospheres.

Unless specifically approved by DOE, no credit may be taken for the use of sorbent cartridges or canisters for protection against radioactive gases and vapors.

High humidity environments may shorten the life of the sorbent material.

2.07.04 Describe the advantages and disadvantages (limitations) of each of the following respirators:

c. Full-face, supplied-air respirator

Atmosphere Supplying Respirators - Air Line

Description:

Air line respirators use a central source of breathing air that is delivered to the wearer through an air supply line or hose. The respirator type is either a tight-fitting facepiece (half face or full) or loose-fitting hood/suit. There are essentially two major groups of air line respirators - the air-line device and the hose mask with or without a blower. Hose masks are not used in power reactors; consequently, further discussion will be limited to demand, pressure demand, and continuous flow air line respirators.

In a demand device, the air enters the facepiece only on "demand" of the wearer, i.e., when the person inhales. During inhalation, there is a negative pressure in the mask, so if there is leakage, contaminated air may enter the mask and be inhaled by the wearer. For this reason, demand respirators are generally no longer used. The pressure demand device has a regulator and valve design such that there is a flow (until a fixed static pressure is attained) of air into the facepiece at all times, regardless of the "demand" of the user. The airflow into the mask creates a positive pressure. The continuous-flow air line respirator maintains a constant airflow at all times and does not use a regulator, but uses an airflow control valve or orifice which regulates the flow of air. The continuous-flow device does not guarantee a positive pressure in the facepiece.

Limitations:

Since the air line respirator provides no protection if the air supply fails, they shall not be used in IDLH atmospheres or for emergency escape or rescue.

The trailing air supply hose severely limits mobility so it may be unsuitable if frequent movement among separated work stations is required.

The length of hose, number of potential users, and pressure of the supply system can reduce the number of allowable users. Control of the air quality is essential to avoid introduction of hazardous respiratory agents to the wearers breathing zone.

"Bubble suits" can aspirate air into the suit when the wearer lifts his arms. Consequently, the suit must be tested for the exact conditions of use.

Special Considerations:

Requirements for use of respirators in "dangerous" atmospheres is specified in 29 CFR 1910.134(e)(3) as follows:

“(3) Written procedures shall be prepared covering safe use of respirators in dangerous atmospheres that might be encountered in normal operations or in emergencies. Personnel shall be familiar with these procedures and the available respirators.

(i) In areas where the wearer, with failure of the respirator, could be overcome by a toxic or oxygen-deficient atmosphere, at least one additional man shall be present. Communications (visual, voice, or signal line) shall be maintained between both or all individuals present. Planning shall be such that one individual will be unaffected by any likely incident and have the proper rescue equipment to be able to assist the other(s) in case of emergency.

(ii) When self-contained breathing apparatus or hose masks with flowmeters are used in atmospheres immediately dangerous to life or health, standby men must be present with suitable rescue equipment.

(iii) Persons using air line respirators in atmospheres immediately hazardous to life or health shall be equipped with safety harnesses and safety lines for lifting or removing persons from hazardous atmospheres or other equivalent provisions for the rescue of persons from hazardous atmospheres shall be used. A standby man or men with suitable self-contained breathing apparatus shall be at the nearest fresh air base for emergency rescue."

Manufacturers of airline respirators include instructions specifying a range of air required to produce at least the minimum required flow rates (4 CFM for tight fitting facepiece and 6 CFM for hoods). These specifications are based on hose lengths and the number of sections connected together. Determining if the proper air flow rate is achieved can be complicated by the use of a breathing air manifold supplying more than one user. The following are recommendations which should be considered.

If all the hose lengths and number of hose fittings are the same, then a manifold with a single regulator and pressure gauge is appropriate for ensuring the proper pressure is used. (Note: If the pressure is within the manufacturer's specifications, then the delivery air flow rate should be at least 4 CFM for tight fitting respirators and 6 CFM for hoods).

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 as follows:

The air flow rate should be measured at the end of the breathing tube (i.e., at the delivery end). This air flow rate should be measured using a calibrated rotameter or equivalent air flow measuring device.

To utilize the Protection Factor (PF) assigned to air supplied hoods, a delivery flow rate of at least 6 CFM but not greater than 15 CFM must be obtained. The individual user's air flow valves should not be altered to maintain a minimum delivery flow rate of 6 CFM as this violates the NIOSH/MSHA approval. Taping or otherwise securing the airflow valves in the fully open position does not void the NIOSH/MSHA approval provided the valve is not permanently altered or made so that it would be impossible to increase or decrease the air flow by the user.

2.07.04 Describe the advantages and disadvantages (limitations) of each of the following respirators:

d. Self-contained breathing apparatus (SCBA)

Atmosphere Supplying Respirators - Self-Contained Breathing Apparatus (SCBA)

Description:

The self-contained breathing apparatus (SCBA) allows the user to carry a respirable breathing supply does not need a stationary air source such as a compressor to provide breathable air. The air supply may last from 3 minutes to 4 hours depending on the nature of the device.

There are two groups of SCBAs - the closed circuit and the open circuit.

Another name for closed circuit SCBAs is "rebreathing" device. The air is rebreathed after the exhaled carbon dioxide has been removed and the oxygen content restored by a compressed oxygen source or an oxygen-generating solid. These devices are designed primarily for 1-4 hours use in toxic atmospheres.

An open circuit SCBA exhausts the exhaled air to the atmosphere instead of recirculating it. A tank of compressed air carried on the back, supplies air via a regulator to the facepiece. Because there is no recirculation of air, the service life of the open circuit SCBA is shorter than the closed circuit system. The only type of open circuit SCBA available for use is "pressure demand".

The pressure demand open circuit SCBA has a regulator and a valve design which maintains a positive pressure in the facepiece at all times regardless of the "demand" of the user. Because of the high degree of protection provided by the pressure-demand SCBA, this type of unit is recommended for emergency use, escape and rescue. There also exist combination atmosphere supplying respirators which utilize supplied air and an SCBA.

- 2.07.04 Describe the advantages and disadvantages (limitations) of each of the following respirators:
- e. Combination atmosphere supplying respirators.

Combination Atmosphere Supplying Respirators

Two types of combination supplying respirators are the combination pressure demand breathing apparatus and the dual purpose breathing apparatus. The combination pressure demand breathing apparatus provides respiratory protection for personnel who must work in atmospheres that are immediately dangerous to life or health (IDLH). When connected to a respirable air source, the device permits the wearer to work and move about freely, within the limits of the approved hose length. The combination pressure demand breathing apparatus is equipped with a small air cylinder which enables the wearer to escape from dangerous atmospheres in case the primary air supply is interrupted.

The apparatus serves as a long duration work device and as an escape device as well. It is approved for respiratory protection for entry into, for extended periods of work in, and for escape from IDLH atmospheres. If used for entry into IDLH atmospheres, the air line must be connected before entry. The self-contained air supply is approved for escape only.

Operation of the combination pressure demand breathing apparatus is manual. It is an approved, rated 5-minute escape device. The pressure demand air line respirator phase is connected by an approved air-supply hose to a primary respirable air source; the worker breathes from this source with the valve of the egress (exit) cylinder of the device turned off until the user is ready to leave the working area. If the primary air supply source should fail for any reason, the worker can switch to the egress cylinder by turning a valve and escape to a safe atmosphere. The worker then can leave, connected to the primary air source, or can open the egress cylinder valve and have approximately five minutes' respiratory protection. When breathing from the air cylinder, the user can remain connected to the primary air supply and exit, or can disconnect from the air source for easier escape.

The dual purpose breathing apparatus combines all the capabilities of a self-contained breathing apparatus and a supplied-air respirator in one unit. The apparatus is approved by the NIOSH and MSHA for use in oxygen deficient atmospheres or where dangerous concentrations of toxic gases or vapors are present. The NIOSH/MSHA approval allows:

- The wearer of the apparatus to enter or exit a dangerous area using only the cylinder air in applications such as emergency rescue
- The wearer to work within the area for a limited time using the cylinder air
- The wearer to work within the area for an extended time using air from a supply line.

Thus, the dual purpose breathing apparatus has all the advantages of both air and work masks. Note particularly that 20% of the cylinder air may be used for entry and that the apparatus is not limited to escape. Of course, if the air from the supply line should fail, the wearer can escape the area using the cylinder air.

The dual purpose breathing apparatus is available in both demand and pressure demand models. In the demand model, air is supplied on demand at ambient atmospheric pressure. In the pressure demand model, a slight positive pressure is maintained within the facepiece during both inhalation and exhalation. The slight positive pressure prevents a toxic atmosphere from leaking into the facepiece; this type of leakage can occur with a demand apparatus due to the negative pressure developed in the facepiece. A pressure demand apparatus should therefore be used where the potential toxicity of the atmosphere is such that no back leakage can be tolerated.

The regulator on the dual purpose breathing apparatus reduces the high pressure from the apparatus's compressed air cylinder to a breathable pressure. In pressure demand models, it also automatically monitors the flow of air into the facepiece so as to maintain a slight positive pressure within the facepiece. The regulator has two inlet ports - one for the cylinder and another for the supply line. A connector allows the air supply to be semi-automatically switched from the cylinder to the air line. With no supply line connected to the regulator, the wearer receives air from the cylinder. When an air line is connected to the regulator through the fitting, the wearer automatically receives air from the supply line. If the air supply from this line should be interrupted, the wearer must disengage the supply line in order to automatically receive air from the cylinder.

Limitations of the Pressure Demand and Demand SCBA. The air supply is limited to the amount in the cylinder and therefore the respirator cannot be used for extended periods without recharging or replacing cylinders.

Because these respirators are bulky and heavy, they are often unsuitable for strenuous work or use in confined spaces.

The demand type SCBA works in a negative pressure mode and is considered obsolete.

Special Considerations of the Pressure Demand SCBA. As specified in ANSI Z88.2, only the pressure-demand type SCBA should be selected for emergency use, rescue, and re-entry into a contaminated area to perform emergency shutdown or maintenance of equipment.

The performance of SCBAs in high temperature environments, such as fires may lead to rapid deterioration of components.

2.07.05 *Define the term protection factor (PF).*

PROTECTION FACTORS

The overall protection afforded by a given respirator design is defined in terms of its protection factor (PF). The PF is defined as *the ratio of the concentration of contaminant in the atmosphere to the concentration inside the facepiece or hood under conditions of use.*

Protection Factors may not be appropriate where chemical or other respiratory hazards exist in addition to radioactive hazards or where the mode of entry is through the skin and not through inhalation. For example, 50% of the intake from exposure to tritiated oxide is through skin absorption. The use of atmosphere supplying respirators will only provide a PF of 2.

Application of PF's is relatively straight forward. The work area airborne radioactivity concentration is divided by the PF to estimate the inhaled concentration. For example, a worker performing steam generator eddy current testing with a full facepiece continuous air flow air line respirator (PF = 1000) and in an atmosphere of 1×10^{-6} $\mu\text{Ci/cc}$ Co-60 would be estimated to inhale a concentration of 1×10^{-9} $\mu\text{Ci/cc}$ Co-60.

Table 1 - Assigned Protection Factors (29 CFR 1910.134)⁵

Type of respirator ^{1, 2}	Quarter mask	Half mask	Full facepiece	Helmet/ hood	Loose-fitting facepiece
1. Air-Purifying Respirator	5	³ 10	50	.....	.....
2. Powered Air-Purifying Respirator (PAPR)	.....	50	1,000	⁴ 25/1,000	25
3. Supplied-Air Respirator (SAR) or Airline Respirator					
• Demand mode	.....	10	50	.....	.....
• Continuous flow mode	.....	50	1,000	⁴ 25/1,000	25
• Pressure-demand or other positive-pressure mode	.....	50	1,000	.....	.....
4. Self-Contained Breathing Apparatus (SCBA)					
• Demand mode	.....	10	50	50	.....
• Pressure-demand or other positive-pressure mode (e.g., open/closed circuit)	.....	.....	10,000	10,000	.....

Notes:

- Employers may select respirators assigned for use in higher workplace concentrations of a hazardous substance for use at lower concentrations of that substance, or when required respirator use is independent of concentration.
- The assigned protection factors in Table 1 are only effective when the employer implements a continuing, effective respirator program as required by this section (29 CFR 1910.134), including training, fit testing, maintenance, and use requirements.
- This APF category includes filtering facepieces, and half masks with elastomeric facepieces.
- The employer must have evidence provided by the respirator manufacturer that testing of these respirators demonstrates performance at a level of protection of 1,000 or greater to receive an APF of 1,000. This level of performance can best be demonstrated by performing a WPF or SWPF study or equivalent testing. Absent such testing, all other PAPRs and SARs with helmets/hoods are to be treated as loose-fitting facepiece respirators, and receive an APF of 25.
- These APFs do not apply to respirators used solely for escape. For escape respirators used in association with specific substances covered by 29 CFR 1910 subpart Z, employers must refer to the appropriate substance-specific standards in that subpart. Escape respirators for other IDLH atmospheres are specified by 29 CFR 1910.134 (d)(2)(ii).

2.07.06 State the difference between a qualitative and quantitative fit test.

RESPIRATOR FIT TESTING

Definitions:

Qualitative fit test: *Test to determine if there is any mask leakage, usually using irritant smoke ("Go/no-go" test but no measured value is assigned).*

Quantitative fit test: *Test to determine quantity of mask leakage and assign a "fit factor," corn oil is the typical challenge atmosphere used (Measures concentration in mask due to leakage against concentration in atmosphere) or a particle counting instrument, such as a Portacount, which counts ambient particles in the air..*

2.07.07 State the recommended physical functions the subject must perform during a respirator fit test.

It is impractical to perform a quantitative fit test prior to each entry requiring respiratory protection. Therefore, qualitative tests are performed to ensure an adequate fit for the user. Qualitative tests can use challenge atmospheres such as Isoamyl Acetate (banana oil) or irritant smoke (e. g., stannic chloride) or as a negative or positive pressure test. The irritant smoke test is the most effective since the wearer's obvious discomfort from the smoke will show leakage through the respirator face seal. However, the test produces noxious odors for not only the wearer but those in the test area. The use of "banana oil" requires a subjective evaluation by the wearer and more often than not a user will not admit that in-leakage has occurred. One reactor respiratory program was faithfully utilizing the banana oil to perform the fit test and virtually all wearers indicated no in-leakage through the facepiece. Unfortunately, the respirator only contained a particulate filter cartridge rather than an organic vapor cartridge. Since most reactors use respirators at many different locations, challenge atmosphere tests are difficult to perform and therefore the "immediately prior-to-use" qualitative test normally selected is to perform a negative pressure test.

Additional factors to be considered in fit testing acceptance criteria are the use of communication devices or sorbent canisters with respirators. The respirator

approval is voided if any communication device is attached to the facepiece, unless the device is listed in the NIOSH/MSHA approval sheet.

In addition to fit testing personnel, the respirator face pieces and cartridges must be periodically tested. Common practices are to test a portion of particulate cartridges upon procurement and to test all particulate cartridges prior to re-use. Anytime the filter is used by a different individual or on a different day by the same individual, the filter is considered as being reused and should be tested for efficiency, resistance and radioactive contaminants. As long as the inhalation valve for the respirator is in place and functions normally, concern for biological contaminants is of the filter is minimal.

The subject performs at least the following functions during fit testing:

- 1) Normal breathing
- 2) Deep breathing
- 3) Moving head from side to side
- 4) Moving head up and down
- 5) Frown
- 6) Talking
- 7) Running in place
- 8) Normal breathing

2.07.08 *State how the term protection factor (PF) is applied to selection of respiratory protection equipment*

SELECTION

Equipment selected must be certified by NIOSH or specifically authorized by DOE. Approvals for respiratory devices are authorized in accordance with 42 CFR 84 and the device, type and certification number are listed in NIOSH publication entitled, Certified Equipment List.

2.07.09 *State the general considerations and considerations for the nature of the hazard when selecting the proper respiratory protection equipment.*

Selection of the proper respirator for any given situation shall require consideration of the following:

- The nature of the hazard
- The characteristics of the hazardous operation or process

- The location of the hazardous area with respect to a safe area having respirable air
- The period of time for which respiratory protection may be provided
- The activity of the workers in the hazardous area
- The physical characteristics, functional capabilities, and limitations of respirators of various types
- The respirator-protection factors and respirator fit

The following factors concerning the nature of the hazard requiring the use of respirators shall be considered in respirator selection:

- The type of hazard
 - Oxygen deficiency
 - Contaminant
- The physical and chemical properties
- The physiological effects on the body
- The peak and average concentrations of toxic material or airborne radioactivity level
- The established permissible time-weighted average or peak concentration of toxic material, or both, or established maximum permissible airborne radioactivity level (or administrative control levels for radiation dose) for radioactive substances
- Whether the hazard is an immediately-dangerous-to-life-or-health concentration of toxic material
- Warning properties

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:

- Identification of the type of respiratory hazard
 - Oxygen deficiency
 - Specific contaminants
- Nature of contaminants
 - Particulate matter
 - Vapors or Gases
- Concentration of respiratory hazard

The following factors concerning the hazardous operation or process shall be taken into account in selecting the proper respirator:

- Operation, process, and work-area characteristics

- Materials, including raw materials, end products, and byproducts (actual and potential)
- Worker activities (Modification in the operation or process shall be taken into account, since this may change the hazard and hence require the selection of a different respirator.)

Selection of air-line respirators includes not only the PF but also the air supply pressure, the air flow to the user and hose length. Each manufacturer's approval sheet lists the approved criteria. For use of 15 to 50 ft of hose at 16 to 20 pounds per square inch, an airflow of greater than 4 CFM to a facepiece, 6 CFM to a hood, and less than 15 CFM to either must be obtained. As discussed, air flow rate delivery should be evaluated for multiple personnel use of breathing air manifolds.

2.07.10 *Identify the types of respiratory equipment available for use at your site.*

SITE RESPIRATORY EQUIPMENT

(Insert site specific material here)

2.07.11 *Identify the quality specifications breathing air must meet.*

AIR QUALITY TESTING

An air quality testing program for all sources of respirable air is required. Compressed breathing air shall meet at least the quality specification for Grade D breathing air as described in Compressed Gas Association Commodity Specification G-7.1-1989.

Section 5 of G-7.1 provides acceptable analytical procedures for measuring the respirable air components. Oxygen is easily measured using standard oxygen detectors which utilize an electrolytic reaction to generate a current proportional to the oxygen content. However, a number of reactors perform the measurement incorrectly as the oxygen percentage is determined by the partial pressures of the oxygen in the monitored atmosphere versus the calibrated atmosphere. The test is often performed by placing the detector probe directly in line with the pressurized supply line. Since the air is measured at an increased pressure, the partial pressure will appear greater relative to the calibration partial pressure and an overestimate of the oxygen concentration will result. A better method is to sample the oxygen in a plastic bag and then insert the probe and withdraw the air

at a reduced pressure condition. Carbon dioxide and carbon monoxide are easily evaluated using either in line continuous monitors or grab sample "indicator tubes". The method at your facility will be determined by the designated Respirator Program Administrator.

The test for condensed hydrocarbons is usually performed by filtering the air, weighing the filter and calculating the concentration by assuming the additional filter weight is due to condensed hydrocarbons. For service air systems, the air quality tests should also include monitoring for radioactive contaminants. The test for radioactive contaminants is necessary as a number of service air and breathing air systems have been cross contaminated from radioactive waste or auxiliary boiler contaminants.

The frequency of performing air quality tests is not specified by regulation or in standards. For bottled air systems, such as SCBAs or respirator air supply cylinders, the tests should be performed on a representative sample of the bottles upon receipt at the facility. For facilities which compress respirable air and fill their own SCBAs, the sampling should be performed prior to each lot fill, once during the lot fill and once upon completion of the lot fill. For compressed air supply systems such as fixed station breathing air systems the sampling frequency is best performed prior to each use of a specific manifold system. However, this may be impractical during a major refueling outage where supplied respirable air is extensively used at different stations. In cases of heavy usage, then a daily check of the system may be more appropriate.

SORBENTS AND PROTECTION AGAINST RADIOIODINES

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 the chemical form of the radioiodine, humidity of the atmosphere, and breathing rate of the user. Approval can be obtained from DOE to use PFs for sorbent cartridges. A criteria for testing and certifying the charcoal cartridges is contained in NUREG/CR-3403, "Criteria and Test Methods for Certifying Air-Purifying Respirator Cartridges and Canisters Against Radioiodine." A brief summary of test conditions and acceptance criteria are as follows in Table 2:

Table 2 - Test Conditions and Acceptance Criteria

<u>Test Parameter</u>	<u>Criteria</u>
Vapor	CH ₃ I
Concentration	1 ppm
Temperature	30 + 1 C
Total Airflow	64 L/min
Equilibration (6H at 64 L/min)	All as received 3 at 50% RH 3 at 75% RH
Maximum Penetration	01 PPM
Minimum Service Life	30 min at 100% RH (extrapolated) 60 min at 75% RH

Limiting conditions of use:

Total challenge in the work place (radioactive iodine, non-radioactive iodine or the halogenated compounds) may not exceed 1 ppm.

Temperature in the work area may not exceed 100 EF. Temperature to be measured on each shift or in conjunction with operations which produce heat in the work area.

Respirator wearers must have demonstrated a fit factor greater than 100 on the full facepiece respirator type to which the GMR-1 is attached.

Service life is 8 hours maximum. This is calculated from the time the canister is unsealed and includes periods of non-use. Once the screw cap on the canister threads or the tape seal over the inlet port on the bottom are removed, the 8 hour use duration begins whether used or not by an individual.

Canisters will not be used in the presence of organic solvents, vapors, or chemicals (such as decontamination compounds, lubricants, volatilized paint, alcohol, freon) which could cause aging, poisoning or desorption of the adsorbed radioiodines. Non-exposure to these organic agents must be demonstrated by usage restrictions and by air sampling.

Canisters must be stored in sealed humidity-barrier packaging in a cool, dry environment (QA Class "A" storage).

COMMUNICATIONS

Although conventional respirators distort the human voice to some extent, adequate communication can be maintained in relatively quiet areas. For power reactors, those areas requiring the greatest use of respiratory protection are often the noisiest due to the numerous pumps, motors and fans. Consequently, special attachments or modifications to the respiratory device are often needed to ensure adequate communication.

A mechanical speech-transmission device, called a speaking diaphragm, is an integral part of the facepiece in some respirators. It usually consists of a resonant cavity and diaphragm which transmit sound. The diaphragm also acts as a barrier to the ambient atmosphere and thus should be handled carefully to prevent possible puncture which would permit leakage of an air contaminant into the respirator. Various methods of electronically transmitting and amplifying speech through the respirator are available. These utilize a microphone connected to a speaker, telephone, or radio transmitter. Usually, the microphone is mounted inside the respiratory-inlet covering, while the amplifier, power pack, and speaker or transmitter are attached to the exterior of the respiratory-inlet covering, carried on the body, or remotely located. Respirators with electronic speech-transmission devices having a battery power supply should be used with caution in explosive atmospheres. Sealed power sources shall be checked for integrity of the seals. Connecting cables from the microphones inside the respiratory inlet covering shall have gas-tight seals where they pass through the covering. When the speaker diaphragm is part of the barrier between the respirator wearer and the ambient atmosphere, it shall be and should be adequately protected from puncture or rupture. A microphone mounted on the respirator wearer's throat or head or a microphone/speaker worn in the respirator wearer's ear does not require penetration of a respirator facepiece by a cable.

Any communication device that is an integral part of the respirator or is attached to the exterior such as a sound transducer on the face plate, must be part of the NIOSH approval for the respiratory device.

SUMMARY

All respiratory protection devices share a common limitation for protection against hazardous substances which injure the skin or eyes (except SCBAs) or are absorbed through the skin. When selecting any protective device, the chemical form of the hazardous substance should be ascertained to determine if skin protection is required and if the eye protection afforded by the respirator is adequate.

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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.

INTRODUCTION

A radioactive source is material used for its emitted radiation. Sources are constructed as sealed or unsealed and are classified as accountable or exempt.

Radioactive sources are used for response checks in the field, functional checks, 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

References:

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

<i>2.08.01 Describe the requirements for radioactive sources as outlined in 10 CFR 835.</i>

In accordance with 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 not 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 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 μCi .
- (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 of 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.

CONTROL OF SOURCES

Types of sources to be controlled include:

- 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.

Responsibilities for controlling these sources include the following:

- 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).

Sources are controlled using the following precautions:

- Each source is to be inspected before each use.
- Remove damaged sources from service.
- Fingers, whether gloved or not, or other objects should never be allowed to touch the active surface of unsealed sources.
- Protect the source from being contaminated when used in a surface contamination area.

2.08.02	<i>Identify the radioactive sources that must be controlled at your site.</i>
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(Insert site specific information here)

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). Upon receipt from radioactive material transportation, external surfaces of packages known to contain radioactive material shall be monitored if the package: (1) Is labeled with a Radioactive White I, Yellow II, or Yellow III label (as specified at 49 CFR 172.403 and 172.436-440); or (2) Has been transported as low specific activity material (as defined at 10 CFR 71.4) on an exclusive use vehicle (as defined at 10 CFR 71.4); or (3) Has evidence of degradation, such as packages that are crushed, wet, or damaged (10 CFR 835.405(b)).

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. This obviates the need to monitor packages being transported from building to building where the person conducting the transport has knowledge that the package has not experienced significant challenges to its integrity (e.g., been dropped, crushed, soaked, etc.)

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.

LABELING AND STORAGE OF RADIOACTIVE SOURCES

2.08.03	<i>Identify the packaging, marking, and labeling requirements for radioactive sources.</i>
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(Insert site specific information here)

Labeling requirements from 10 CFR 835 include:

- (a) Items and containers may be excepted from the radioactive material labeling requirements of 10 CFR 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 precautions to avoid or control exposures; or
 - (2) The quantity of radioactive material is less than one tenth of the values specified in Appendix E of 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 §835.601(a)

Sealed radioactive sources not in storage containers or devices and not labeled by the manufacturer must be clearly marked with a radiation symbol and have a durable label/ tag containing the following information:

- Radionuclide
- Amount of activity
- Name of manufacturer
- Date of assay
- Model and serial numbers (where available)

RADIOACTIVE MATERIALS AREAS

2.08.04 *Describe the approval and posting requirements for radioactive materials areas.*

(Insert site specific information here)

Definitions from 10 CFR 835 for posting of radioactive materials areas include:

- (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))

§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) Areas may be excepted from the radioactive material area posting requirements 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 this subpart 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 labeled and in non-degraded condition need not be posted in accordance with §835.603 until the packages are monitored in accordance with §835.405.

In addition, storage rooms or cabinets containing radioactive sources should meet the following:

- Locked and posted
- Located to minimize damage from fire
- Free of flammable substances
- Isolated from occupied areas or located in radiological areas or radiological buffer areas
- 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

Gamma radioactive sources (except small counting radioactive sources that are low energy and low activity or well shielded) should be stored separate from locations where radiation detection/counting equipment is present.

SOURCE DISPOSAL

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

SUMMARY

Sources may be sealed or unsealed, accountable or exempt. Controls for sources are governed by DOE requirements. Responsibility for source control is delineated in contractor procedures. The RCT needs to be knowledgeable of controls used to prevent contamination and minimize exposure. All on-site sources require prior written approval. Accountable sources are identified, inventoried, surveyed and tested (sealed only). The use and disposition of sources is maintained on records.

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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.

INTRODUCTION

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. This data can then be analyzed, and such information as critical nuclides and critical pathways can then be determined. The Radiological Control organization is generally interested in determining activity in the ambient air, in surface water and sediments, in ground water wells, as well as ambient dose rates in the environment.

Another aspect of environmental monitoring that concerns all employees is the identification of suspect waste sites. When a waste site is suspected, it is the responsibility of the employee to report the site to the proper site authorities for restoration and remediation efforts.

References:

1. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5th 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.

2.09.01 *State the goals of an environmental monitoring program.*

GOALS OF AN ENVIRONMENTAL MONITORING PROGRAM

The following are goals of an environmental monitoring program. Each is described in the subsequent pages.

1. Estimate Human Population Doses
2. Determine Site Impact
3. Detect and Quantify an Unplanned Release
4. Meet Legal or Regulatory Requirements
5. Create and Maintain a Good Public Image
6. Obtaining Pathway Data
7. Test Adequacy of Radiological Control Measures
8. Study of Air and Water Mixing Patterns
9. "Non-Industry" Applications

Estimate Human Population Doses

ALARA dictates that we must be aware of changes in radiation exposure to the general population which results from nuclear operations. Issuing TLD's to the population is not practical. In addition the TLD's are not sensitive enough to detect changes in environmental radiation levels. The only practical way to determine population exposure is by measurement of environmental radiation levels:

- External radiation level
- Radioactivity present in air
- Radioactivity present in food
- Radioactivity present in water

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.

2.09.02 *State the exposure limits to the general public as they apply to environmental monitoring.*

Determine Site Impact (DOE Order 5484.1 and DOE/EH-0173T)

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.

Environmental levels are then measured during site operation. Changes are tracked to determine site impact. The exposure of members of the public to radiation sources as a consequence of all routine DOE activities, outside of controlled areas, 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 from radionuclides taken into the body during the year. 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. 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.

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.

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.

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.

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.

Detect and Quantify an Unplanned Release

Although adequate Radiation Safety programs are maintained at all sites, there is always the possibility of an "unknown release." Environmental monitoring can serve as a secondary backup system to the primary defense of a good Radiation Safety program.

- Windscale reactor fire in 1957 detected by I-131 detected downwind of the site.
- Chernobyl detected by the Western powers through environmental monitoring programs in Europe.

Meet Legal or Regulatory Requirements

DOE regulations dictate environmental monitoring requirements for facilities. Larger facilities and plants are required to maintain continuous, extensive monitoring programs according to DOE requirements, Federal and State regulations, and regulatory guides. DOE Order 5820.2A requires monitoring of all inactive, existing, and new low-level waste (LLW) disposal sites to assess both radiological and nonradiological hazards. DOE Order 5820.2 requires monitoring and maintenance of all surplus facilities prior to decontaminating or decommissioning.

Create and Maintain a Good Public Image

Operating an environmental monitoring program more extensively than required by law shows the licensee to be a "good neighbor." Extensive environmental monitoring also provides added protection against lawsuits.

2.09.03	Define the term "critical nuclide."
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Obtaining Pathway Data

Department of Energy facilities, while striving to reduce releases of radioactive material or isotopes to the environment to zero, do occasionally make planned or unplanned releases. Among the many radionuclides that can be released from a site, we can identify a small group of radionuclides which, if released, would cause the largest dose contribution to the public. 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 "critical nuclides" for an operational nuclear reactor include:

- Actinium-227
- Barium/Lanthanum-140
- Cesium-137
- Cobalt-60
- Hydrogen-3 (Tritium)
- Iodine-131
- Plutonium-238
- Plutonium-239
- Manganese-54
- Radium-226
- Strontium-89
- Strontium-90
- Thorium-230
- Thorium-232

2.09.04 *Define the term "critical pathway."*

In order for any of these radionuclides to contribute dose to the public, there must be a way for the nuclides to move from the site to the public. A "pathway" is any route that radioactivity can follow in passing from a site to a person in the general population where it becomes internally deposited or contributes external dose. *A **critical pathway**, then, is the route taken, from the point of release to body entry, of a critical radionuclide which causes human exposure.*

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.

Test Adequacy of Radiological Control Measures

Small amounts of non-routine radionuclides beginning to show up in the environmental samples could indicate problems at the site. Radiological Controls and operations at the site can then be reviewed and tightened prior to any releases above the prescribed limits.

Study of Air and Water Mixing Patterns

To aid in the study of transport mechanisms, small amounts of radioisotopes are sometimes released under controlled conditions to determine air and water pathways. This data is used in determining population dose estimates.

"Non-Industry" Applications

- Atmospheric and oceanic circulation studies.
- 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 bringing in topsoil from other areas, the use of fertilizers, plowing the ground, the addition of water to the ground, the presence of structures, and a whole host of other changes that people make. Many of these changes may significantly alter the radionuclide content in the area. The addition of water to the ground or the presence of buildings can serve to attenuate radiation, but may also introduce new radionuclides to the area. Industrial activities can also result in the emission of naturally occurring radionuclides to the air or water, which results in a redistribution of radioactivity.

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. Prior to operating a site, an environmental monitoring program will be run in order to document ambient radiation levels that exist in the environment prior to the new site's start up. We can also locate any naturally occurring radiation anomalies in the environment. We document meteorology patterns, and use this information to help identify critical nuclides and critical pathways for the new site.

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 monitoring program with enough sensitivity to detect environmental changes in radioactivity.
- 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 of the post-operational can be focused primarily on the critical nuclides, and the instrumentation on the critical pathways.

RADIOLOGICAL CONTROL RESPONSIBILITIES

Radiological Surveys are Conducted to Monitor Radioactive Contamination

General Monitoring Requirements:

- Ambient air in the immediate vicinity of active and inactive sites.
- Surface water (rivers, estuaries, lakes and oceans) and sediments are monitored for constituents indicating the status of operational practices and control.
- Soil and vegetation are monitored to detect possible contamination from fallout and uptake.
- Ground water wells are surveyed to ensure their physical integrity.
- Background dose rates are monitored near facilities that may have elevated dose rates.
- Radiation surveys are performed to detect contamination spread. 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.

Appropriate documentation must be completed for each environmental survey.

2.09.05 *State locations frequently surveyed for radiological contamination at outdoor waste sites associated with your site and the reasons for each.*

Radiological Surveys are performed on:

(Insert site specific information here.)

2.09.06 *Define the term "suspect waste site," and how they can be identified.*

SUSPECT WASTE SITES

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.

Suspect Waste Site Identification

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. The following conditions should be looked for:

- Soil discoloration is present
- An unusual soil depression or disturbance exists
- Pipes emerging from the ground (indicates a possible crib, tank or other structure).
- Plant stress
- The unusual absence of plant life
- Vaults, chambers, concrete or steel structures, drums, pipes, or munitions protruding from the surface of a disturbed area
- Holes, sinkholes, or collapsed structures (indicates the presence of man-made structures or voids beneath the surface)
- The presence of hazardous and/or radioactive material in soil samples
- Documentation or personnel interviews which indicate the past existence of a waste disposal site.

ANALYSIS OF ENVIRONMENTAL SAMPLES

Environmental sample types include:

- Air samples
- Soil samples

- Vegetation samples
- Animal samples
- Surface water samples
- Groundwater samples
- Background radiation
- Radiation surveys

Methods of Monitoring

Environmental levels of external gamma radiation are measured using film or thermoluminescent dosimeters. The lower detection level for film badges is approximately 10 mrem/month. The lower detection level for TLD's is approximately 1 mrem a month. Corrections must be made, however, for fading of 1 mrem/month dependence.

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.

Fallout simply means radioactive particles that settle out onto the ground. The term does not necessarily imply a nuclear detonation has occurred.

"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.

Rain water is also collected and analyzed for radioactivity that may have been washed from the air.

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).

OTHER TYPES OF ENVIRONMENTAL SAMPLES

Atmospheric sampling is accomplished in several ways depending on the physical properties of the airborne radioactivity, such as the chemical properties of the activity and the phase of the activity (particulate or gas or vapor):

- **Air sampling for particulates**

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

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. 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. The rate at which air (particles) is drawn through the filter also is a factor in collection efficiency. 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. 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. Radon and Thoron may mask actual activity of the filter, however, some counting methods can avoid this problem.

- **Air sampling for gases**

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.

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.

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.

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.

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.

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. Radionuclides such as Co-60 and Zn-65 concentrate in shellfish. Consumption of oysters from Willapa Bay, Washington, proved to be a pathway for Zinc-65 from the Hanford reactors even though the oyster beds were 30 miles from the mouth of the Columbia River and the reactors over 200 miles upriver from the mouth of the Columbia River.

Sampling should be done if these radioactive fission products are discharged into an estuary populated with shellfish. If I-131 is released, cow pastures should be sampled as well as the milk produced. I-131 will appear in the milk within 24 hours. The need for analysis of food increases near nuclear facilities. Regional and national monitoring programs continue to be required due to fallout from weapons testing.

2.09.07	<i>Describe the methods used for environmental monitoring at your facility.</i>
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SITE ENVIRONMENTAL MONITORING PROGRAMS

(Insert site specific information here.)

TRANSPORT MECHANISMS

Atmospheric Transport

Airborne radioactive contaminants are carried downwind and dispersed by normal atmospheric mixing processes. Internal irradiation occurs if the radionuclides are inhaled and incorporated in the body. External irradiation occurs by beta and gamma irradiation from the plume. Material is removed from the plume by impaction of the plume with the ground surface or by washout due to rain. Deposition of the material from the plume leads to further exposure pathways through:

- Direct external exposure from contaminated surfaces
- Inhalation of re-suspended material
- Ingestion of contaminated foodstuffs.

Factors considered in determining the deposition of radioactive material back to earth include:

- Wind speed
- Temperature
- Stack height
- Particle size
- Weather conditions.

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:

- A warm front covers a cooler earth
- A cool front is injected under warm air (sea breeze)
- The normal cycle of a summer day when the earth cools off faster than the air above.

Surface Water Transport

Liquid effluents may be discharged into various types of surface water bodies: rivers, estuaries, lakes and oceans. In rivers, the rate of transport is slower than in the atmosphere. Radionuclides may be absorbed by bottom sediments, and may accumulate in the aquatic biota. Although these two processes involve only a small fraction of the inventory, they may be significant with respect to radiation exposure.

Radioactive materials released in rivers eventually feed into the ocean. In the ocean surface layer (75m in depth and located above the thermocline) the mixing time is 3-5 years. Below the thermocline in the deep ocean, the mixing is much slower.

Some aquatic mixing factors include:

- Depth of water
 - Type of bottom
 - Shoreline configuration
 - Tidal factors
 - Wind
 - Temperature
 - Salinity
 - Solubility of radioactive material
-
- Depth at which pollutant is introduced.

Movement in the Ground

Radionuclide movement in the ground is generally the slowest. Movement of most radionuclides depends upon convective transport in water. 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. 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.

RADIOISOTOPES OF CONCERN

Plutonium (Pu-239)

Pu-239 is tightly bound by soils and is present in plants in only minute amounts. Very small amounts of Pu-239 are transferred to plants through root uptake. Plutonium has a tendency to stick to any material in which it comes in contact. The critical organ for Pu in the insoluble oxide compound is the lung. If Pu is in soluble form and ingested, the critical organ is the bone.

Properties of Pu-239:

Radiological half-life (Tr): 24,400 years

Biological half-life (Tb): 203 years

Effective half-life (Te): 200 years

Sources: Produced in thermal reactors by neutron irradiation of U-238. In nuclear weapons and as fuel for fast reactors.

Radiation, Energy (MeV): α (alpha), 5.15, 5.14, 5.10

Chemistry: Member of the Actinide series of rare-earth elements. Forms insoluble fluorides, hydroxide, and oxides; soluble complexes with citrate and nitrate.

Effective Half Life of Pu is shown in the following formula:

$$T_e = \frac{T_r \times T_b}{T_r + T_b}$$

Strontium (Sr-89, Sr-90)

Rainfall increases the fallout of strontium from the atmosphere. It appears to build up the greatest in the soils with a high exchangeable calcium content. The strontium content of plants is due in part to uptake from soil and in part from foliar deposition. The dietary sources of strontium depend partly on the food consumption habits of the population and the manner in which the food is processed or prepared. The bone is the critical organ for Sr-89 and Sr-90.

Properties of Sr-90:

Radiological half-life: 28.1 years

Biological half-life: 50 years

Effective half-life: 17.8 years

Source: Fission product

Radiation, Energy (MeV): β^- , .546 Mev

Chemistry: Alkaline earth element similar to calcium

Iodine (I-131)

Because of the short half-life of I-131 (8 days), it is not a significant environmental contaminant insofar as its uptake from the soil is concerned. The decay rate is relatively rapid in relation to the growing time of a crop, and any significant contamination by means of root uptake would, for this reason, be improbable. Radioiodine deposited on the surfaces of plants can be ingested directly by cattle and passed in this way to milk or other dairy products. Since the time between collection and consumption is relatively short, the possibility of iodine contamination of fresh milk must be considered. Contamination of

powdered milk is less of a problem because a longer storage time will permit decay of the isotope. Fresh fruit and vegetable stands may also be a potentially important source to local populations. I-131 is soluble and readily absorbed through skin, lungs, and GI tract. The critical organ is the thyroid.

Properties of I-131:

Radiological half-life: 8.05 days

Biological half-life: 138 days

Effective half-life: 7.6 days

Sources: Fission product

Radiation, Energy (Mev): β^- , .606 ; γ , 0.364

Chemistry: I-131 is a halogen element. The milk content of I-131 reaches its peak 3 days after deposition. The effective half-life of removal from grass is 5 days.

Cesium (Cs-137)

Cesium-137 is bound so tightly by the clay minerals of the soil that the root uptake is slight, and foliar absorption is, therefore, the main method of entry to the food chains. The uptake of Cs-137 from the soil has been shown to be inversely proportional to the potassium deficiency. Although cow's milk is the largest single contributor of Cs-137 to the U. S. adult diet, other foods including grain products, meat, fruit, and vegetables contribute 2/3 of the dietary Cesium intake. The critical organ is the whole body.

Properties of Cs-137:

Radiological half-life: 30 years

Biological half-life: 45-150 days

Effective half-life: 45-150 days

Source: Fission product

Radiation, Energy (Mev): β^- , 0.514 ; γ , 0.662

Chemistry: Alkali metal with properties similar to potassium (K) and Rubidium (Rb); most salts are soluble.

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.

INTRODUCTION

This lesson reviews Radiological Work Permits, various types of postings used in radiological areas, setting up radiological areas, access controls, and releasing of material from radiological areas.

References:

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

RADIOLOGICAL WORK PERMITS (RWP)

2.10.01 State the purpose of and information found on a Radiological Work Permit (RWP) including the different classifications at your site.

(Insert site specific information here)

The RWP is an administrative mechanism used to establish radiological controls for intended work activities. The RWP informs workers of area radiological conditions and entry requirements and provides a mechanism to relate worker exposure to specific work activities. The RWP should include the following information:

- Description of work
- Work area/process radiological controls
- Dosimetry requirements
- Pre-job briefing requirements, as applicable
- Training requirements for entry
- Protective clothing and respiratory protection requirements
- Radiological control coverage requirements and stay time controls, as applicable
- Limiting radiological conditions that may void the RWP
- Special dose or contamination reduction considerations
- Special personnel frisking considerations
- Technical work document number, as applicable
- Unique identifying number
- Date of issue and expiration
- Authorizing signature

Radiological Work Permits are required for activities such as entry into High or Very High Radiation Areas, entry into High Contamination Areas, or any entry into Airborne Activity Areas.

Other activities that might require the use of a RWP include entry into Radiation Areas, entry into Contamination Areas, or handling of materials with removable contamination that exceeds the values in Table 2-2 of the Radiological Control Standard..

2.10.02 *State responsibilities in using or initiating a RWP.*

(Insert site specific information here)

Workers accessing an area permitted by an RWP are required to sign the RWP or log prior to initial entry and after any revisions to the RWP. This process signifies that the worker has read the RWP. The workers signature signifies that he/she is aware of the radiological conditions and agrees to comply with the requirements.

There are basically two types of RWPs, Job-specific and General. General RWPs govern routine or repetitive work where radiological conditions are stable such as general inspections, surveillances, surveys, and tours. General RWPs may be used to govern specific maintenance and operations when such jobs do not involve work with elevated or complex radiological conditions. General RWPs are typically valid for one year. Job-specific RWPs are used to control nonroutine operations or work in areas with higher level or changing radiological conditions. Job-specific RWPs usually remain in effect only for the duration of the job.

ALARA CONSIDERATIONS FOR ACCESS CONTROL AND WORK AREA SETUP

Exposure to ionizing radiation is typically quantified, tracked, and controlled in terms of the equivalent dose workers receive, or could potentially receive, in given situations. Management policy is to maintain radiation exposure of employees, subcontractors, visitors and members of the general public not only within applicable DOE and administrative limits, but "As Low as Reasonably Achievable."

2.10.03 *State the document that governs the ALARA program at your site.*

Documentation

(Insert site specific information here)

2.10.04 Describe how exposure/performance goals are established at your site..

Exposure/Performance Goals

(Insert site specific information here)

PRE-JOB ALARA REVIEWS

2.10.05 State the conditions under which a pre-job ALARA review is required at your site.

Pre-job ALARA reviews are required to be held prior to the conduct of work anticipated to exceed trigger levels. An example of this would include a work area with removable beta/gamma contamination levels greater than 100,000 dpm/100cm².

Pre-job meetings are held with employees who will be involved in work activities involving unusual radiological conditions. These meetings allow an open discussion of all the factors identified as effective dose reduction measures. RC needs are communicated to workers. Worker needs are communicated to RC. Procedures are verified, worker qualifications are verified, and what they do in an emergency is discussed. At the end of the meeting, everyone should know what is expected of them, how to do it, and the conditions under which it is to be done.

Pre-job briefings are usually conducted by the cognizant work supervisor and as a minimum, the pre-job briefings should include:

- Scope of work to be performed
- Radiological conditions of the workplace
- Procedural and RWP requirements
- Special radiological control requirements

- Radiologically limiting conditions, such as contamination or radiation levels that may void the RWP
- Health Physics/Radiological Control Hold Points
- Communications and coordination with other groups
- Provisions for housekeeping and final cleanup
- Consideration of potential accident situations or unusual occurrences and a review of abnormal and emergency procedures and plans
- Emergency response provisions.

Site requirements for pre-job reviews:

(Insert site specific information here)

POST-JOB ALARA REVIEWS

2.10.06	<i>State the conditions under which a post-job ALARA review is required at your site.</i>
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Post-job ALARA reviews 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.

As a minimum, the post-job ALARA review should include the following, as applicable:

- Any changes/modifications made to original work instructions.
- Time required to perform the job.
- Resources required for job.
- Estimated collective dose versus actual collective dose summary.
- Effectiveness of exposure controls implemented.
- Problems encountered and solutions.

- Abnormal events/situations causing the use of stop work.
- Lessons learned.
- Actions taken to prevent recurrence of problems or situation.

An example of when a post-job ALARA review is required is when a job has had actual doses 30% higher than expected.

Site requirements for post-job reviews:

(Insert site specific information here)

RADIOLOGICAL POSTINGS

2.10.07 State purpose of all radiological postings, signs, labels, and barricades; and the RCTs responsibilities for them.

The purpose of radiological postings, signs and labels is to identify items or areas that have the potential for, or actually contain, radiological hazards; identify the radiological hazard(s) present in an area and to prevent workers from inadvertently entering radiological area(s), and/or mishandling radioactive materials.

Each individual is responsible to read and comply with all the information identified on radiological postings, signs and labels. 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.

All access points into an area must be posted to ensure workers are adequately warned of the hazards in the area. Postings and status boards (if applicable) should be promptly updated after completion of a survey to reflect the corrected conditions in the area.

If necessary, the RWP should be amended to reflect any changes in the area. 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.

Radiological Control Technicians should immediately update postings after performing a survey. The RWP and any status boards must also be updated. If the posting was updated and the RWP was not, a worker may consider the RWP correct and the posting wrong. If a worker entered the area based on the incorrect RWP information he/she could become contaminated or receive unnecessary radiation exposure.

Areas should be posted if there is a strong potential for the situation to exist, even if it is not now present. 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 personnel contamination or unplanned internal exposure.

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.

Disregarding any radiological posting, sign or label can lead to unnecessary or excessive radiation exposure and/or personnel contamination.

Unauthorized removal or relocation of radiological postings, signs and labels may lead to disciplinary actions up to and including job termination. If any type of material used to identify radiological hazards is found outside a RBA, it should be reported to radiological control personnel immediately. The RCT would then perform a survey of the sign, posting or label and conduct a survey of the area in which it was found.

Any contamination or higher than expected radiation levels must be promptly reported to the RCT supervisor.

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 Storage Area*
- l. Underground Radioactive Material Area*

TYPE OF RADIOLOGICAL POSTINGS, SIGNS AND LABELS

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 (0.5 millisievert) in one hour at 30 cm from the source or from any surface that the radiation penetrates.

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

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 m from the source or from any surface that the radiation penetrates.

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 derived air concentration (DAC) values listed in Appendix A or Appendix C of 10 CFR 835; or (2) an individual present in the area without respiratory protection could receive an intake exceeding 12 DAC-hours in a week.

10 CFR 835 requires the following:

1. §835.601 General Requirements
 - (a) Areas shall be posted in accordance with this subpart to provide warning to individuals of the presence, or potential presence, of radiation and/or radioactive materials.
 - (b) Except as provided in §835.602(b), postings and labels required by this subpart shall include the standard radiation warning trefoil in black or magenta imposed upon a yellow background.
 - (c) Signs required by this subpart shall be clearly and conspicuously posted and may include radiological protection instructions.
 - (d) 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.
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. The words “Caution, Radiation Area” shall be posted at each radiation area.
 - (b) High Radiation Area. The words, “Caution, High Radiation Area” or “Danger, High Radiation Area” shall be posted at each high radiation area.
 - (c) Very High Radiation Area. The words “Grave Danger, Very High Radiation Area” shall be posted at each very high radiation area.
 - (d) Airborne Radioactivity Area. The words “Caution, Airborne Radioactivity Area” or “Danger, Airborne Radioactivity Area” shall be posted at each airborne radioactivity area.
 - (e) Contamination Area. The words “Caution, Contamination Area” shall be posted at each contamination area.
 - (f) High Contamination Area. The words “Caution, High Contamination Area” or “Danger, High Contamination Area” shall be posted at each high contamination area.
 - (g) Radioactive Material Area. 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.

Area designations

(Insert site specific information here)

Entry Requirements

(Insert site specific information here)

SETTING UP RADIOLOGICAL AREAS

2.10.09 Describe good practices, support equipment to use, and common discrepancies in setting up radiological areas.

Good practices to be considered whenever possible in setting up Radiological Areas: establish walkways in low dose areas; do not store radioactive materials near walkways or where personnel frequently work; 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.

Use drip trays or containment devices to prevent the spread of contamination. Establish laydown areas for equipment to limit personnel safety hazards and/or radiation exposure. Set up SOPs upwind of contamination hazards. Post all accessible sides and entrance(s) to areas containing radiological hazards.

Use Personnel Contamination Monitors (PCMs) along with portable contamination survey instrumentation whenever possible. PCMs are more likely to detect contamination on individuals because personnel tend to survey too quickly. If this happened with an actual contamination incident the employee could subsequently pass over the contamination areas with the portable contamination survey instrumentation.

The following are commonly observed discrepancies that should be avoided in the setup of Radiological Areas:

- Posting information not updated or information otherwise incorrect.
- Boundaries not verified for contamination, radiation, and airborne radioactivity hazards.
- Survey instruments out of calibration or defective.
- Step-off-pads not set up for efficient removal of protective clothing (not enough room to prevent contaminating the SOPs) and not near survey instrumentation.
- Laundry and waste receptacles not placed for efficient use or not placed at all. Receptacles not properly labeled as to their contents.
- Boundaries of areas setup too far from the hazards interfering with access to areas otherwise unaffected.
- Count rate meters not located close to the step-off-pads.
- Status boards or survey maps do not reflect where SOPs and boundaries lie.
- Status board not kept up-to-date. The information on status boards, postings and RWPs should agree. Postings should be updated at least every 24 hours while an RWP is in use and reflect current radiation and contamination levels in the area.
- Tripping hazards exist from wires, hoses, or cables.
- Background radiation in monitoring area too high for efficient detection of low level contamination.

- Portable contamination survey instrumentation not set up for proper operation.
- Protective clothing (gloves and booties) not readily available in a personnel contamination event.
- Phone or other communication devices not available near the SOP or portable contamination survey instrumentation.
- Not posting all access points into area.
- Failure to post dress and undress procedures.

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:

- Step-off-pads.
- Portable contamination survey instrumentation/personnel contamination monitors to establish at exits to Contamination Areas, Airborne Radioactivity Areas, and RBAs.
- Yellow and magenta rope, ribbon or tape.
- Laundry receptacles.
- Waste receptacles (clean and radioactive waste receptacles).
- Receptacles for defective protection clothing (optional).
- Receptacles for non-compactable waste (optional).
- Receptacles for mixed waste (optional).
- Electrical power supply and extension cords (optional).
- Postings, signs, labels, and posting inserts.
- Communication equipment readily available.
- Additional protective clothing.

- Dose rate meters and smears.
- Survey maps.

CONTAINMENT DEVICES

2.10.10 List discrepancies frequently observed in containment devices.

Containment devices include glove boxes, glove ports, hot cells, huts, and windbreaks. Common discrepancies observed in containment devices include:

- Holes/leaks in the containments or is maintained at a positive pressure, facilitating the spread of contamination.
- Liquids accumulating in hoses or main portions of the containment.
- Airlocks too small to remove protective clothing without spreading contamination.
- Ventilation exhaust not directed to the plant ventilation system.
- Material allowed to accumulate inside containments, limiting safe and/or efficient use.
- Sharp objects used inside containments.
- Devices not tethered to prevent introduction into systems.
- Transfer sleeves/ports are not used or are unavailable.
- Containment not provided with a HEPA filter or ventilation exhaust.
- Containments not periodically surveyed inside and out.
- No means of quickly verifying loss of ventilation.
- Containment not decontaminated prior to dismantling.
- Adequate access not provided for lines or hoses.

- Containment not maintained at a negative pressure.
- Containment not supported properly to minimize stress from minor ventilation changes or not structurally supported to maintain its configuration during use.
- Containments not inspected prior to use and periodically during use.
- Not using appropriate containment devices for leaks.
- Not using a funnel to collect leakage.
- Plastic components showing fatigue or wear.
- Funnel not positioned to collect all leaking fluid.
- Drain lines kinked allowing the buildup of liquids.
- Drain lines not secured properly to the collection device.
- Containment device not labeled to indicate hazards that are present.

PORTABLE VENTILATION SYSTEMS

<i>2.10.11</i>	<i>Describe good practices in setting up portable ventilation systems and count rate meters.</i>
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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.

Good practices to be used for the set-up of portable ventilation systems include:

- Use only HEPA (High Efficiency Particulate Air) filters with pre-filters (roughing filters)
- Perform radiation survey on filters periodically while in use.
- Have radiological limits established for filter replacement.
- Exhaust filter discharge to the plant ventilation system whenever possible.

- Ensure that there are no openings in the trunk or between the blower and the filter.
- Monitor the filter differential pressure (d/p) periodically.
- Establish filter d/p at which the filter must be replaced.
- Remove filters into plastic bags to prevent the release of activity.
- Position streamers to signify the flow of ventilation through doorways or through containment devices.

CONTAMINATION MONITORING EQUIPMENT

The proper setup and use of portable contamination survey instrumentation 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:

- They must be placed in low background area.
- They need reliable power supply.
- They should be positioned to facilitate easy access by workers.
- Alarms should be set to site administrative control levels or DOE limits.
- Must ensure instrument is source checked and calibrated.
- Extension cords must be checked for electrical safety.
- Portable contamination survey instrumentation and PCMs should be placed upwind of contaminated areas.
- They should not be placed near radioactive material storage areas or other areas where the background radiation can change.
- Portable contamination survey instrumentation should have sources provided to source check the instrument.

ACCESS CONTROL

10 CFR 835 requires the following:

§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.

§ 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.

Entry and Exit Requirements for Radiological Buffer Areas

2.10.12 List the requirements individuals must follow while working in RBAs.

(Insert site specific information here)

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.

- Workers who receive radiation exposures from other nuclear facilities must report the exposure to site radiological control personnel and their supervisor upon returning to the site.
- Avoid contact with potentially contaminated surfaces.
- Any management/supervision or site radiological control personnel should give stop work or evacuation orders if unanticipated radiation or contamination is encountered or if the appropriate RWP is not being followed.
- Wear dosimeter(s) in accordance with the RWP.
- Maintain exposure ALARA.
- Report all injuries.
- Monitor clothing and exposed skin as required and report the presence of radioactive contamination.
- Place contaminated items and waste in approved radioactive waste containers.
- Personnel should wash their hands when leaving the RBA and prior to eating or using tobacco products.
- Personnel who are not respiratory qualified should not enter areas posted as "Respiratory Protection Required"

Hot Particles

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.

- The Site-Specific Radiological Control 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.
- Special surveys in areas with the potential for hot particle contamination.
- Posting areas to specifically identify the presence of hot particles.
- Controlling access to hot particle areas should through a job-specific RWP. The following controls should be considered for inclusion on the RWP:
 - Periodic personnel monitoring during the work activity, at a frequency based on the potential magnitude of skin exposure
 - Additional Personal Protective Equipment and Clothing
 - Direct Radiological Control coverage during work or assistance during protective clothing removal
 - Use of sticky pads or multiple step-off pads.
- 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.
- Response to hot particle skin contamination of personnel should include the following:
 - Immediate removal and retention of the hot particle for subsequent analysis
 - Analysis of the particle
 - Assessment of worker dose
 - Evaluation of work control adequacy.

REMOVING MATERIALS FROM RADIOLOGICAL AREAS

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.

<p>2.10.13 <i>State the requirements for removing or releasing materials from any radiological area.</i></p>

Release to Radiological Buffer Area

(Insert site specific information here)

Release to Uncontrolled Areas

(Insert site specific information here)

SUMMARY

This lesson addressed radiological area support and access control. The areas covered included RWPs, radiological postings, setting up radiological areas, good practices and discrepancies commonly observed in setup of various portions of radiological areas, access control, and removing materials from radiological areas.

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.

INTRODUCTION

Jobs performed in restricted areas are usually approved and controlled by radiological control personnel by using administrative and procedural controls, such as Radiological Work Permits (RWPs). In addition, some jobs will require working in, or will have the potential for creating, very high radiation, contamination, or airborne radioactivity areas.

REFERENCES

1. DOE Radiological Control Standard (2008).

PURPOSE OF JOB COVERAGE

2.11.01 List four purposes of job coverage.

Job coverage by RCTs generally has four purposes:

1. To ensure worker's radiation exposures are maintained ALARA and within limits/guidelines
2. To minimize the creation and spread of surface contamination.
3. To minimize the creation and spread of airborne radioactive material.
4. To minimize the creation of radioactive waste.

TYPES OF JOB COVERAGE

2.11.02 Explain the differences between continuous and intermittent job coverage.

Job (or work) coverage can either be continuous or intermittent. During **continuous** job coverage, the technician covers only one job and remains at the job site while work is being performed. For **intermittent** coverage the technician may cover more than one job, performing periodic checks at various work locations.

CONDITIONS REQUIRING JOB COVERAGE

2.11.03 Given example conditions, identify those that should require job coverage.

Some radiological conditions or types of jobs that could require radiological control job coverage are:

- Radiation dose rates in the job area are high enough to potentially cause workers' doses to exceed administrative control levels in a short time.
- Radiation levels are expected to increase significantly during the job.
- Entry into high radiation areas.
- The potential for spreading high levels of contamination or causing airborne radioactivity.
- The potential for significant increase in contamination or airborne radioactivity levels during the job.
- Inadequate personnel dosimetry for the type or levels of expected radiation (e.g., neutrons or low-range dosimeters).
- Jobs performed by inexperienced workers.

PREREQUISITES/WORK PLANNING

2.11.04 Identify items that should be considered in planning job coverage.

To effectively cover a job, technicians must preplan their activities. Items that should be included in the planning include:

- Determine exactly what workers will be doing (e.g., not just "replace a component" but the details of whether grinding, cutting or welding will be performed).
- Review old surveys and talk with technicians who have previously covered the same or similar jobs to anticipate any problem areas.
- Review the area and system on which the work will be performed, or talk with the workers to determine the potential radiological consequences of the tasks associated with the job (e.g., opening a cask / container could create contamination, airborne radioactivity, or cause radiation levels to change).

- Ensure that an adequate survey of the job area has been made.
- Review applicable post-job ALARA reviews.

When sufficient survey documentation is not available, a pre-job survey is usually required. This is a detailed survey performed at the job site before the job begins that is used to determine RWP requirements. This survey should include dose rate, contamination and representative breathing zone air samples for the areas being accessed. The survey should identify the highest and lowest dose rate areas. All individuals, including the technician, should stay in the low dose rate areas as much as possible.

- For jobs in which workers' dose limits could be approached, record the allowable exposure for each worker. A good practice is to have this information available at the job site.
- Establish communication methods with the workers prior to the job. Workers should know how, when, where, and why to contact the RCT.

For most jobs communicating with workers is simply a matter of talking face-to-face. However, for some jobs remote communications (e.g., headsets, or a safety line attached to a belt) may be required. Hand signals may be needed when respirators are worn. Two way portable radios are another option for communication.

- Establish a method of communicating with and transferring samples to the radiological control counting lab.

Often an air sample taken during the job must be transferred from the job site to the radiological control lab for analysis. Arrangements for transferring samples, and obtaining results, should be made before the job begins.

- Have the appropriate equipment available at the job site.

Examples include extra dosimeters, dosimeter charger, air sampler and filters, a survey instrument, respirator (if needed), watch or clock for time keeping, extra gloves, and any other equipment required by the job.

Consideration of Other Hazards

When evaluating the hazards for a job, it is important to consider non-radiological hazards as well. A framework aligned with the principles and functions of Integrated Safety Management (ISM) requires systematic 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 107th 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.

2.11.05 Identify examples of information that should be discussed with workers during pre-job briefings.

- Pre-job briefing of the workers before going to the job site.

Proper pre-job briefings **10 CFR 851 Worker Safety and Health Program**

On December 2, 2002, the 107th 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.

10 CFR 851 provides for a worker health and safety program for DOE contractors and should be addressed in hazard analysis evaluation for radiological operations.

include the technician (or line supervisor) informing workers of radiological conditions such as: dose rates, contamination levels, and concentration of airborne radioactivity in the work area. This should include an explanation of the probable effect of their job on radiological conditions. Other important points could include method of communications that will be used, specifics about special dosimetry or protective clothing and actions of the technician covering the job. The RCT should cover what actions and exits to take in an emergency to reduce worker exposure and confusion. Worker questions should be answered prior to starting work. The technician should emphasize radiological safety and the importance of following the RWP and it's specific directions.

JOB COVERAGE TECHNIQUES

2.11.06 Describe exposure control techniques that can be used to control worker and technician radiation exposures.

The techniques in covering a job will depend upon the nature of work being done, the radiological conditions present or expected in the work area, and to some extent the experience of the workers. The following sections describe job coverage techniques that may be applicable.

Exposure Control

One of the purposes of job coverage is to keep track of the dose received by workers and suggest methods that the workers can follow to keep their doses ALARA. At the same time, the technicians must take measures to minimize their own dose as well. Pre-job surveys alone are not always adequate in determining the dose rates to personnel during the job. Many jobs will require that surveys be performed as the job progresses. The purpose and type of surveys should be based on the level of the conditions and their probability of change. Surveys provide information about current conditions and if the conditions are changing. Surveys can identify unusual conditions which may lead to changing job requirements or even stopping the job. It is just as important to record the results of job coverage surveys as recording the results of the routine and pre-job surveys. In addition, do not keep this information to yourself or merely log and file the survey records. Keep the personnel in the area informed of the radiological conditions. Technicians should explain to the workers why actions are being taken. The following is a list of some of the techniques that can be used to help maintain exposure control:

- Wait in low dose rate areas while not actually performing the job.

Remember that surveys of job areas should always identify low dose areas. To reduce the amount of time spent in higher radiation levels and consequently reduce the dose received, both technicians and workers should stay in the lower dose rate areas whenever possible (e.g., waiting for equipment, when resting, when visual observation of workers is possible from a distance).

- Periodically read or have workers read their dosimeters.

To keep track of the dose accumulated by the workers the technician should read or have the workers read their dosimeters. If several workers are working on the same job, select one individual to read the others' dosimeters. The individual that reads the dosimeters can remove one outer glove or slip on a clean glove to lessen the chance of contaminating the dosimeters.

- Use workers' allowable dose and the dose rate in an area to determine the length of time a worker can spend in the area.

For jobs where workers will approach an administrative control or DOE limit, the technician will have to determine how long a worker can remain in an area without exceeding the authorized exposure. Detailed surveys will determine the dose rate. The workers dose limits can be obtained from dosimetry records. The following formula is used to determine the amount of time the worker can stay in the area:

$$\text{TIME ALLOWED} = \frac{\text{A l l o w a b l e D o s e}}{\text{D o s e R a t e}}$$

Remember to tell the individual to leave before the total time has elapsed. It takes some time for the workers to respond and they may receive significant dose going to and from the job location.

- When using time to control workers' dose, an accurate record of the workers location with respect to the dose rate must be maintained.

On some jobs (e.g., working in a neutron radiation field) keeping track of how long the worker is in the radiation field (Dose = Dose Rate x Time) will be used to determine the dose received by the worker. The technician must record the workers' locations with respect to the dose rate to accurately calculate the dose.

- Write down the workers location and time in that location when time keeping.

Relying on memory can be inaccurate. Record the times in the area.

- Observe the location of workers' dosimetry with respect to the location of the radiation source.

On some jobs, the workers' heads, back, or other parts of the body could be receiving higher dose than the chest area where dosimetry is normally worn. Relocating the workers' dosimetry or obtaining additional

dosimetry may be required to obtain the highest dose received to the whole body.

- Workers must leave temporary shielding in place unless they have been authorized to remove the shielding by Radiological Control.

Unauthorized movement of shielding could increase the dose rate in the work area.

- Technicians performing job coverage should move temporary shielding only after evaluating the effect of such movement and with proper approval.
- Perform your survey as objects are being removed from their shipping container or cask, don't wait until the radioactive objects are withdrawn to make the survey.
- Keep workers from leaning across or over high sources of radiation. Possibly get them to move to the other side of equipment to do their work.
- Prevent workers from picking up sources of radiation with their hands. They should use pliers or tongs, and carry items in a bucket or a plastic bag rather than in the hand.
- Anytime casks, containers or equipment are being opened (or opened further than before) recheck radiation levels, including beta radiation levels.

In-progress radiological surveys

2.11.07	<i>Describe the in-progress radiological surveys that should be performed, at your site, under various radiological conditions.</i>
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In-progress radiological surveys that should be performed should be performed as specified by the controlling technical work document and Radiological Work Permit (i.e., smear surveys, dose rate surveys, air samples taken).

(Insert site specific information here)

In-progress radiological survey documentation

2.11.08	<i>Describe site requirements for documentation of in-progress radiological surveys.</i>
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Radiological Control personnel should maintain logs to document radiological occurrences, status of work activities and information that should be communicated to all personnel. Make field notes of survey results for later documentation. Good practice dictates that all surveys should, at a minimum, be documented on the appropriate map.

(Insert site specific information here)

Unexpected radiological conditions

2.11.09	<i>Explain actions that should be taken if surveys show radiological conditions significantly different from that expected.</i>
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(Insert site specific information here)

2.11.10	<i>Describe contamination control techniques that can be used to limit or prevent personnel and area contamination and/or reduce radioactive waste generation.</i>
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Contamination Control

By observing the actual performance of the job, technicians can suggest methods that could help prevent spreading contamination from one area to another and could lessen the probability of personnel contamination. The following items should be considered:

- Watch the workers. Point out and correct any work habits that could spread contamination.

Even though all workers are trained in basic methods to prevent spreading contamination during their initial Radiological Worker training course, many workers either forget the techniques or lapse into more familiar but contamination spreading work habits. Such habits include hand-to-face movements, dropping tools, scuffing feet, hammering, and wire brushing. Technicians must identify actions that will spread contamination, ask the worker to stop the action, and explain why the actions should be stopped.

- System components that are being repaired should be wiped down and drained before the system is opened.

Even though operations personnel may have drained a specific part of the system, the workers should have plastic buckets, bags, and plastic sheeting to contain any residual water when the system is opened.

- Ensure that workers follow procedures for transferring material from the radiological area to either a Radiologically Controlled Area or a clean area.

They should hold the bag over the contaminated area, only touch the outside of the bag with clean gloves, place (not drop) items into the bag, not overload the bag, tape sharp edges before placing in bag and not lay the bag down in the contaminated area. Tape the bag shut and mark the bag indicating what it contains. Large items can be covered with plastic sheeting that is taped in place after all surfaces have been wiped off. Wheels on carts, trolleys and cranes can be heavily taped or plastic/paper sheeting laid down between contaminated areas to create a temporary pathway across a clean area.

Do not allow bags of trash, tools or used parts to accumulate in the work area or at the step off pad or control point. Obtain dose rate and contamination surveys of all bagged or covered items being removed from the work area before they are moved when dose rates in the area allow.

- Ensure workers follow proper procedures to minimize contaminating tools and equipment.

By reducing the chances of contaminating tools and equipment, the probability of spreading contamination plus the cost, radiation exposure, and manpower involved in decontamination can be lessened. Techniques such as taping or bagging tools

and pulling welding leads, hoses and extension cords into plastic tubing before beginning work or using tools already contaminated should be suggested by the technician. The reasons for the suggestions should be explained.

- Watch for the movement of crane rigging, air or water hoses, electric leads and extension cords into and out of contaminated areas.
- Electrical lines and hoses going into Contaminated Areas should be secured (taped down) to eliminate the possibility of movement in or out.

Any of the above movements could spread contamination. Be alert for such movements and explain why they should not be made. If overhead

cranes are going to be used, suggest methods to lessen the spread of contamination (e.g., papering floors along the pathway that the crane will take).

- Have workers remove their outer layer of protective clothing (gloves, shoe covers, and coveralls) a few feet prior to the step off pad area.
- Reduce the creation of radioactive waste.

Reduction of radioactive waste will assist in preventing the spread of contamination and airborne radioactive material and reduce the cost and manpower involved in processing and shipping radioactive material offsite for burial. Before going into the Radiological Area, have the workers remove the packaging for any new equipment they will be carrying into the area. During performance of the job, suggest that a minimum amount of water be used, if required. Point out to the workers other areas where creation of radioactive waste can be reduced.

2.11.11 *Describe job coverage techniques that can be used to prevent or limit the spread of airborne radioactive material.*

Airborne Radioactivity Control

When the creation and spread of airborne radioactivity can be controlled, the use of respiratory protection equipment can be minimized. By watching workers and monitoring for airborne radioactivity during a job, technicians can suggest methods that can prevent creating airborne or warn workers when airborne radioactivity is present. Appropriate corrective actions (e.g., respiratory protection, evacuation of work area, stay times) can be implemented. As in exposure and contamination control, the technicians should explain the actions required to the workers. The following items should be considered:

- Look for any actions that could create airborne radioactivity.

Such actions could include opening systems containing radioactive material; leaks or sprays from the system, welding, grinding, cutting on contaminated systems; or

any actions that could disturb highly contaminated surfaces (e.g., hammering, wire brushing, or use of pneumatic tools). Warn the workers and take appropriate corrective actions.

- Take air samples during jobs in highly contaminated areas or at steps (e.g., opening a system to change HVAC filters) that could create airborne radioactive material during a job.

During the performance of such jobs, workers will usually be in respirators as a precautionary measure. Analysis of the air sample can be used to determine the necessity of respirators and to calculate the number of DAC-hours received by the workers.

Remember to get the sample counted and obtain the results as quickly as possible. A grab air sample only tells you what the average airborne radioactivity concentration was in the area while the sampler was running.

- Use a continuous air monitor (CAM) during performance of a job that is likely to create airborne radioactivity.

CAM results give an immediate indication of an increase in the airborne radioactive material concentration. Appropriate protective action for CAM alarms includes evacuation of all affected personnel and notification of Radiological Control. Re-entry into affected areas should include the use of respiratory protection.

- Ventilate enclosed areas.

By ventilating enclosed areas, airborne radioactive material generated in the area can be removed. "Enclosed areas" include permanent cubicles or rooms or temporary tents built to enclose work areas. Ventilation can be obtained via the installed in-plant ventilation system or by using portable fans or blowers with HEPA filters.

In certain job situations the use of respiratory protection can increase the total equivalent dose for the job. This is referred to as "dose expansion." Dose expansion occurs when respirator usage increases time in a radiation/high radiation/very high radiation area to the extent more dose is received than dose from an internal dose commitment from not wearing respiratory protection.

2.11.12

Describe overall job control techniques in maintaining control of radiological work.

Overall Job Control Techniques

In the preceding three sections, the specific guidelines for controlling exposure, contamination and airborne radioactive material were discussed. In addition to maintaining control over these three specific areas, technicians must maintain overall control of the radiological aspects of the job.

- Establish worker trust and confidence.

Worker trust and confidence are not automatically gained by being the RCT covering the job. Trust and confidence must be earned by each technician and the entire plant radiological control staff. Characteristics of technicians and health physics departments that will assist in earning worker trust include being reliable, credible, realistic, and consistent.

- During job coverage, the technicians should keep workers within their line of sight, if possible.

While not possible at all times (e.g., when workers and technician are separated by a shield wall), the technician should constantly be observing the workers. Poor work habits possibly leading to the spread of contamination, creation of airborne radioactive material, and unnecessary exposure to radiation can be identified and corrected.

- Keep in contact with the workers.

The technicians should talk with the workers to remind them that they are covering the job and are available to answer questions or make suggestions. This is especially important if remote communications equipment is being used, since the workers may be apprehensive.

- Remind workers that casks, containers or systems are not to be opened or work techniques changed without notifying radiological control.

Explain that these actions could change radiological conditions in the area and cause unnecessary exposure to radiation or airborne radioactive material or cause the spread of contamination.

- When an individual's work habits must be corrected, offer the correct method as advice or help.

No worker enjoys being told that his method of doing a job is incorrect. A belligerent, demanding approach by the technician can result in more harm than benefit. Explain why the workers' method is incorrect and what the possible consequences are and then offer the correct method as another

solution. Remember that as a technician your role is to assist the workers in maintaining their exposures ALARA.

- Show a positive, helpful attitude toward co-workers.

If workers note that the technician is complacent or disinterested in the job, the workers may become lax in following the proper procedures for reducing their exposure and preventing the creation and spread of contamination or airborne radioactive material. The technicians covering the job should take an interest in the job being performed by the workers and take pride in their own work.

- Do not overreact to situations when there is time for levelheaded solutions. Getting excited and yelling at workers for minor problems will only result in the workers losing any respect for the radiological control staff. Calmly explain what the problem is and the steps that need to be taken to correct the situations. Reserve excitement for true emergencies.

2.11.13 *State the reasons to stop radiological work activities in accordance with the DOE RCS.*

Stop Work Authority

- The DOE RCS gives Radiological Control personnel the authority and responsibility to stop work when there are:
 - Inadequate radiological controls
 - Radiological controls not being implemented
 - Radiological hold points not being satisfied
 - Alarming dosimetry or unexpected dosimetry readings
- Exercise your authority to stop work with discretion. Remember it is your responsibility to ensure that the work is performed safely in a radiological environment. The following situations are examples of when work should be temporarily halted to correct problems:
 - Workers disobeying procedures or not following their RWP
 - Dropped container incidents / spills
 - Unexpected dose rates or surface contamination readings.
- Resumption of radiological work requires approval from the line manager responsible for the work and the Radiological Control Manager.

SUMMARY

This lesson addressed radiological work coverage. The areas covered included the conditions requiring job coverage, the prerequisites and planning involved, and techniques associated with the coverage of radiological work.

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.

RADIOACTIVE MATERIAL SHIPMENT REGULATIONS

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.

<i>2.12.01 List the applicable agencies which have regulations that govern the transport of radioactive material.</i>

Regulatory Structure. 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.

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:

- 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.

- DOE O 460.1B – Establishes administrative procedures for the certification and use of radioactive and other hazardous materials packaging by DOE. 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.
- DOE Order 460.2A – 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.

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.

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.

2.12.02 *Define terms used in DOT regulations.*

DEFINITION OF TERMS

In order to understand the regulations, it is necessary to understand the basic language and limits established in the regulations. The following definitions are found in 49 CFR 173.403 (this is not a complete listing of the §173.403 definitions):

A₁. The maximum activity of special form radioactive material permitted in a Type A package.

A₂. The maximum activity of radioactive material, other than special form, Low Specific Activity, or Surface Contaminated Object, permitted in a Type A package.

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.

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.

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.

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_2 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 $10^{-6}A_2/g$.
- 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 $2 \times 10^{-3}A_2/g$.

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.

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 A₁ or A₂ 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.

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.

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.

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^2 (or the area of the surface if less than 300 cm^2) does not exceed 4 Bq/cm^2 (10^{-4} microcurie/ cm^2) for beta and gamma and low toxicity alpha emitters, or 0.4 Bq/cm^2 (10^{-5} microcurie/ cm^2) for all other alpha emitters;
 - ii) The fixed contamination on the accessible surface averaged over 300 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed $4 \times 10^4 \text{ Bq/cm}^2$ (1.0 microcurie/ cm^2) for beta and gamma and low toxicity alpha emitters, or $4 \times 10^3 \text{ Bq/cm}^2$ (0.1 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 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed $4 \times 10^4 \text{ Bq/cm}^2$ (1.0 microcurie/ cm^2) for beta and gamma and low toxicity alpha emitters, or $4 \times 10^3 \text{ Bq/cm}^2$ (0.1 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 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed 400 Bq/cm^2 (10^{-2} microcurie/ cm^2) for beta and gamma and low toxicity alpha emitters, or 40 Bq/cm^2 (10^{-3} microcurie/ cm^2) for all other alpha emitters;
 - ii) The fixed contamination on the accessible surface averaged over 300 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed $8 \times 10^5 \text{ Bq/cm}^2$ (20 microcurie/ cm^2) for beta and gamma and low toxicity alpha emitters, or $8 \times 10^4 \text{ Bq/cm}^2$ (2 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 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed $8 \times 10^5 \text{ Bq/cm}^2$ (20 microcurie/ cm^2) for beta and gamma and low toxicity alpha emitters, or $8 \times 10^4 \text{ Bq/cm}^2$ (2 microcurie/ cm^2) for all other alpha emitters.

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.

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.

Type B Quantity. A quantity of radioactive material greater than a Type A quantity.

APPLICATION OF REGULATORY REQUIREMENTS

The following is a general discussion of the steps followed to:

- Determine the type and quantity
- Determine the activity and radiation levels
- Package
- Mark, label, and placard
- Surveys of packages and transport vehicles
- Prepare shipping papers.

These steps are for a typical shipment of radioactive material. This discussion is not all inclusive of every regulatory requirement and is intended only as an explanation of the major transportation considerations.

Each individual responsible for transfer, packaging or shipping should become familiar with the regulations and other regulatory documents and establish clear, step-by-step instructions in the form of procedures for workers to follow.

If the radioactive material is in a physical or chemical form that constitutes a hazard in addition to the radiological hazard (such as an acid, base, toxic or flammable substance), additional regulations could apply to the packaging, shipment and disposal of the material. This type of waste is known as "Mixed Hazardous Waste." Additional requirements for Mixed Waste are specified in DOT, EPA, and state regulations.

2.12.03	<i>Describe methods that may be used to determine the radionuclide contents of a package.</i>
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Radioactive Contents. 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.

Identification and quantitative measurement of most gamma emitting isotopes is fairly simple using gamma energy spectroscopy techniques. It is much more difficult to identify and measure beta and alpha emitting radionuclides.

Recognizing these problems, the NRC issued technical papers and other guidance on radionuclide identification techniques. The NRC position papers state that there are four basic methods which are considered acceptable for radionuclide identification. These methods are materials accountability, classification by source, gross radioactivity measurements, and direct measurement of individual radionuclides.

The materials accountability technique is 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. For example, if the concentration of airborne radioactivity entering and leaving a HEPA filter is measured and the air volume passing through the filter is known, the difference can be assumed to be retained in the filter.

The classification by source method involves determining the radionuclide content through knowledge and control of the source of the material. For example, a sealed calibration source that was leaking and had to be returned to the manufacturer could be assumed to contain the same isotope and quantity of radioactive material as when it was received, provided that source control and inventory procedures are adequate to ensure traceability of the material (i.e., to prove that the sealed source being shipped is the same one that was received).

Measurement of gross radioactivity (e.g., based on a dose rate from a container) is an acceptable method for radionuclide identification provided that:

- The gross radioactivity measurements are correlated to the actual radionuclides in the material.
- The gross measurement is initially correlated to actual radionuclide content and periodically verified.

The final acceptable method for determining radionuclide content is by direct measurement. In this method, individual gamma emitting radionuclides are directly measured using gamma spectroscopy. Concentrations of other radionuclides are projected by determining their ratio to the concentration of gamma emitting radioisotopes. The ratios are usually referred to as scaling factors. This method is essentially the same as the gross measurement method except for the quantitative measurement of the individual gamma emitting isotopes.

2.12.04 Describe the necessary radiation and contamination surveys to be performed on packages and state the applicable limits.

Package Radiation Surveys and Limits

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):
 - i) The shipment is made in a closed transport vehicle;
 - ii) The package is secured within the vehicle so that its position remains fixed during transportation; and
 - iii) 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.

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:

2.12.05

Describe the necessary radiation and contamination surveys to be performed on exclusive use vehicles and state the applicable limits.

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

Contaminant	Maximum Permissible Limits		
	Bq/cm ²	μCi/cm ²	dpm/cm ²
Beta and gamma emitters and low toxicity alpha emitters	0.4	10 ⁻⁵	22
All other alpha emitting radionuclides	.04	10 ⁻⁶	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.

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.

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:
 - i) The shipment must be exclusive use;
 - ii) The quantity of radioactive material in each packaging may not exceed an A₂ 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.

Type A Packages

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

- a) 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.
- b) The smallest external dimension of the package is not less than 10 centimeters (4 inches).

Type B Packages.

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

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

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.

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

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.

2.12.06 *Identify the proper placement of placards on a transport vehicle.*

Proper Placarding of Transport Vehicle.

Do not over-label or placard a vehicle unnecessarily. Application of such placard when the hazard does not exist is a violation of regulations.

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)).

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.)

2.12.07 *Identify inspection criteria that should be checked prior to releasing a shipment at your site.*

Inspection Prior to Release of Shipment

(Insert site specific information here)

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

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. Most Department of Defense facilities that use radioactive materials, for example, are licensed by the NRC.

VIOLATIONS OF REGULATIONS

Increased public awareness of issues concerning the nuclear industry including the associated activities of shipping radioactive material and disposing of radioactive waste, has led to increased political activity in creating new laws, regulations, and acceptance criteria along with increased inspection activities. Violations of regulations are considered "serious." Many personnel within the nuclear industry who are not aware of all of the regulatory requirements are putting themselves, and others, at risk. Ignorance of the requirements and lack of attention to detail has led to many violations. Keeping current with the latest requirements, periodically reviewing all requirements, creating and enforcing current procedures to clarify methods of compliance, and inspecting shipments before they leave the facility is no longer a part time job. Personnel assigned the responsibility of packaging and shipping radioactive material must realize the seriousness and consequences of even a minor infraction of the 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.

2.12.08	<i>Describe site procedures for receipt and shipment of radioactive material shipments.</i>
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RECEIPT OF RADIOACTIVE MATERIAL

10 CFR 835 requires the following:

§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:
 - (1) Take possession of the package when the carrier offers it for delivery; or
 - (2) 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:
 - (1) 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
 - (2) Has been transported as low specific activity material on an exclusive use vehicle (as these terms are defined in 10 CFR 71.4); or
 - (3) 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.

It is necessary that packages of radioactive material be expeditiously delivered and that the existence of a leak be rapidly detected to minimize radiation exposure to transportation and plant personnel, to minimize the spread of contamination and to aid in identifying personnel and property that may have been exposed or contaminated during the transport of the radioactive material. Prompt and careful inspection of packages containing radioactive material is required by DOE O 460.2A. If the inspection results in even the suspicion that the package may have been damaged in transit, surveys for removable contamination are required.

(Insert site specific information here)

SHIPMENT OF RADIOACTIVE MATERIAL

(Insert site specific information here)

2.12.09	<i>List the actions required at your site if a shipment is received exceeding radiation or contamination limits.</i>
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SHIPMENT EXCEEDING LIMITS

Action When Limits Are Exceeded. 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)

2.12.10	<i>Describe the proper step-by-step method for opening a package containing radioactive material at your site.</i>
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OPENING PACKAGES OF RADIOACTIVE MATERIAL

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

(Insert site specific information here)

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.

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.

INTRODUCTION

Many people believe "it can't happen here" or "it won't happen to me" and do not take incident response planning seriously. But, incidents do occur, and experience has shown that the best response comes from workers who have prepared themselves with a plan for dealing with incidents. Each incident may be unique and no plan can be expected to give an exact solution to every problem, but a step-by-step approach for responding to a problem will help assure an appropriate response.

REFERENCES:

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

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

RADIOLOGICAL INCIDENTS AND EMERGENCIES

A radiological incident is an unplanned event involving radiation or radioactive materials (part of an emergency). The response taken to an incident is usually governed by normal procedures.

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.

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.

Causes of radiological incidents and emergencies could be one or more of several reasons:

- Ignorance
- Forgetfulness
- Oversight
- Unforeseen circumstances
- Communications failures
- Mechanical failures
- Human error
- Natural disasters

Having general guidance on response and a general plan of approach is good ALARA philosophy, because part of an appropriate response is the risk incurred by the responders and those involved as well as what is deemed to be an "acceptable" risk.

2.13.01	<i>Describe the general response and responsibilities of an RCT during any incident.</i>
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GENERAL RESPONSE TO EMERGENCIES

Although Health Physics personnel respond to an emergency using basic guidelines, an area or site may have specific procedures which have priority over these guidelines. Health Physics 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. Even with general or specific guidelines one's actions may change depending on the severity of an incident or whether one is a first responder, one of many responders, or a backup person.

The basic emergency response guidelines are:

- 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.
- Attempt to stop the cause of the emergency. No undue risks should be taken. One must always be aware that careless action may cause them to become part of the problem.
- Notify facility management and safety personnel. Minor incidents that can be handled by a single responding person may only require a telephone call when the opportunity presents itself. If more than one person is needed for an appropriate response, activation of a site emergency response network (such as dialing "911") is the manner in which notification should be given.
- Warn personnel in the area of the emergency. This keeps unnecessary personnel away from the event site, minimizing their exposure and risk.
- 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, internal and external exposure rates, potential for criticality, possible spread of radioactive contamination or other hazardous material, weather conditions, non-radiological hazards, and security (site security may assist in establishing boundaries). Outside the exclusion area normal operations may continue. Enlist whatever resources and personnel that are available to accomplish isolation and be prepared to help others in this endeavor even if there is no radiological risk.
- Minimize personnel exposure. During the 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 are guidelines for control of emergency exposures:
 - Up to 10 rem for protecting major property and where lower dose limit is not practicable.
 - Up to 25 rem for lifesaving or protection of large populations where lower dose limit is not practicable.

- Above 25 rem for lifesaving or protection of large populations. Only on a voluntary basis to personnel fully aware of the risks involved.
- Secure ventilation. Close entrances, windows, and the supply ventilation systems as necessary. Remember that most facilities are designed for proper ventilation and frequently one merely has to ensure that the design condition are being met such as closing doors, windows, and other openings that should not be open. One should only alter designed ventilation if it is obvious that ventilation and improper air flow patterns are contributing to the incident and impeding bringing it under control. Even with the conclusion to change ventilation, one should consult with facility management to determine the impact of changing ventilation on other activities that may be affected.
- Perform surveys. Health Physics personnel are trained to perform emergency surveys. The types of surveys will vary with the nature of the emergency. Good quality surveys take time. Do not short cut or speed up surveys unless a real need such as a medical need exists.
- Initiate the recovery. This includes clean-up operations, decontamination and moving the exclusion area barricade inward.

The RCT is the Health Physics person on site that has the experience, instruments, and the responsibility for radiation safety and other personnel will seek them out for answers. Be prepared to respond with answers, directives, and/or suggestions. Don't assume others will automatically know what to do. Debriefings for lessons learned typically obtain good information from the initial responders to incidents.

2.13.02 *Identify any emergency equipment and facilities that are available, including the location and contents of emergency equipment kits.*

FACILITIES AND EQUIPMENT

(Insert site specific information here.)

RCT's should always know the resources and equipment available to them in the area where they are working. These resources include the physical location, people, equipment, and communications.

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.

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.

2.13.03 *Describe the RCT response to a Continuous Air Monitor (CAM) alarm.*

RESPONSE TO A CONTINUOUS AIR MONITOR (CAM) ALARM

Airborne radioactivity may be caused by a breach in a system, or resuspension of particulate radioactivity due to work evolutions such a 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.

Initial Response

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

Supplementary Actions (re-entry)

- Upon re-entry, don respiratory equipment and protective clothing based on conditions of the event
- Evaluate the affected area by taking an air sample, measuring radiation levels, and checking for CAM malfunction
- Obtain additional air samples as necessary to determine boundaries and maintain access control
- Identify isotope(s) to help determine problem source and protective measures

- Consider additional ventilation to minimize personnel exposure and reduce the need for respiratory equipment (HEPA)
- Measure and control surface contamination to minimize the spread of contamination
- Survey exhaust systems, ventilation filters, and ducts. Have decontamination performed as necessary to minimize contamination spread
- Evaluate the potential for internal exposure and contact facility dosimetrist for proper internal dosimetry protocol
- Personnel should be interviewed for information on any off-normal event which could have caused the alarm
- Take air samples, once operations resume, to verify that the cause of airborne activity has been corrected

(Insert site specific information here.)

2.13.04 Describe the RCT response to a personnel contamination monitor alarm.

RESPONSE TO PERSONNEL CONTAMINATION MONITOR ALARM

Initial Response

- Instruct affected worker to remain in area (standfast).
- Report to the scene with at least portable instruments for direct surveys and smear media.
- Perform whole body surveys (frisk) for the appropriate type of radiation (alpha and/or beta-gamma).
- Take actions to minimize cross-contamination, such as covering or placing a glove over a contaminated hand.

Supplemental Actions

- Survey affected area to characterize the extent of contamination.
- 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.

- 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.
- Refer to facility specific procedures if contamination persists.
- 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.

- Report all confirmed skin contaminations to RCT supervision and refer to your facility specific procedures if transporting to a medical facility.
- Gather appropriate information for follow-up surveys.

Follow-up actions

Shall be in accordance with the site procedure. These typically include:

- 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.
- 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.)

2.13.05	<i>Describe the RCT response to off scale or lost dosimetry.</i>
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RESPONSE TO OFF-SCALE OR LOST DOSIMETRY

Off-scale Self Reading Personal Dosimeter

- 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.
- Alert others working in the area.
- 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.
- 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.

Lost Dosimetry

For lost dosimetry, typical actions include:

- Individual(s) must leave the area if dosimetry is required.
- Contact RCT supervision for reissue of dosimetry.

Supplemental Actions

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

(Insert site specific information here.)

<p>2.13.06 <i>Describe the RCT response to rapidly increasing, unanticipated radiation levels or an area radiation monitor alarm.</i></p>
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RESPONSE TO RAPIDLY INCREASING, UNANTICIPATED RADIATION LEVELS OR AN AREA RADIATION MONITOR ALARM

Initial Response

- Evacuate personnel as quickly as possible to a safe area (low dose area).
- Measure radiation levels in affected area.

- 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.
- Evaluate the situation. The best contact is people at the scene.
- Verify postings and boundaries are adequate.

Supplemental Actions

- Verify personnel staging area dose rates are acceptable and check individual exposures. Notify RCT supervision of results.
- Re-occupy area upon approval of line/facility management.
- Document all surveys using appropriate forms.

(Insert site specific information here.)

2.13.07 <i>Describe the RCT response to a dry or liquid radioactive material spill.</i>

RESPONSE TO DRY OR LIQUID RADIOACTIVE SPILL OF KNOWN MATERIAL AND ORIGIN REQUIRING SWIMS

(Insert site specific information here.)

- **STOP** the spill. Take appropriate precautions that are dependent on the situation. All spills are different. Correct the situation immediately if possible without taking undue risks.
- **WARN** other personnel. Let people around know what is going on. If the situation warrants, evacuate the area. Notify your supervisor, facility 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.
- **ISOLATE** the area. Establish boundaries and post the area around the spill area for exposure and contamination control.

- **MINIMIZE** exposure to yourself as well as others. Practice ALARA principles and use all protective gear available.
- **SECURE** ventilation by controlling HVAC (heating, ventilation, air conditioning). 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.
- **FOLLOW THROUGH** as necessary by starting and collecting air samples as may be indicated, surveying for contamination, and decontaminating. The cleanup of 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. Complete all documentation of surveys and logs.

If you are unsure if you can contain the spill, or if you do not know the nature of the spill, use the “WIN” process:

- **Warn** others
- **Isolate** the area, keep personnel out
- **Notify** authorities

2.13.08	<i>Describe the RCT response to a fire in a radiological area or involving radioactive materials.</i>
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RESPONSE TO A FIRE IN A RADIOLOGICAL AREA OR INVOLVING RADIOACTIVE MATERIALS

(Insert site specific information here.)

Typically Radiological Control will supply support to the Fire Department and will be represented at the Command Post.

2.13.09	<i>Describe the RCT response to other specific site incidents (as applicable).</i>
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RESPONSE TO OTHER FACILITY SPECIFIC INCIDENTS

(Insert site specific information here.)

2.13.10 Describe the response levels associated with radiological emergencies.

EMERGENCY RESPONSE LEVELS

(Insert site specific information here.)

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:

- Level of control over hazardous materials.
- Safety or security of a nuclear weapon, component, or test device that would not pose an immediate threat to workers or the public.
- Safety or security of a facility or process that could, with further degradation, produce a Site Area Emergency or General Emergency.

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:

- Major failure of functions necessary for the protection of workers or the public.
- 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.
- Major degradation in level of safety or security of a facility or process that could, with further degradation, produce a General Emergency.

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:

- Catastrophic reduction of facility safety or security systems with potential for the release of large quantities of hazardous materials to the environment.
- 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.

2.13.11 Describe site specific procedures for documenting radiological incidents.

DOCUMENTATION OF RADIOLOGICAL INCIDENTS AND EVENT CATEGORIZATIONS

(Insert site specific information here.)

2.13.12 Identify the structure of the emergency response organization at your site.

EMERGENCY RESPONSE ORGANIZATION

(Insert site specific information here.)

2.13.13 Identify the available offsite incident support groups and explain the assistance that each group can provide.

OFFSITE SUPPORT GROUPS

(Insert site specific information here.)

2.13.14	<i>Discuss radiological incidents at the plant or other plants, including cause, prevention, and recommended incident response.</i>
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SITE SPECIFIC LESSONS LEARNED

(Insert site specific information here.)

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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.

INTRODUCTION

In our work environment, one of the major concerns of radiological control is the prevention of personnel contamination. When personnel contamination has been identified, it is the responsibility of the RCTs to perform or oversee the decontamination of the individual using the best methods available. Frequently, the RCT is also required to document the decontamination effort and make any required notifications. This lesson will address the methods used to detect personnel contamination. In addition, it will address the factors which determine decontamination actions, the responsibilities of the RCTs and the approved methods for decontamination of personnel.

References:

(Insert site specific references.)

PERSONNEL CONTAMINATION

The potential for personnel contamination is normally monitored via one of the following methods:

External Contamination

- Hand Held Count Rate Meters
- Partial Body Monitors
- Personnel Contamination Monitors.

Internal Contamination

- Whole Body Counts/In Vivo Monitoring
- Bioassay Samples.

When monitoring for external contamination, hand held count rate meters may be used in one of two ways. Personnel may survey themselves for contamination, or allow radiological control personnel to conduct the survey for them. The majority of external contamination surveys are completed using hand held count rate meters.

Another method of surveying for external contamination is using some type of contamination monitoring machine. Two basic types of monitors exist, partial body monitors and whole body monitors. Partial body monitors, such as hand-and-shoe monitors, a half body monitor, or a portal (walk through) monitor, monitor only a portion of the body. As such, partial body monitors should only be utilized for spot-checking for personnel contamination. To conduct a whole body survey, a personnel contamination monitor that surveys the entire body should be used.

Internal contamination may be monitored in one of two ways. The first method includes whole body counts and specific organ counts (lungs, thyroid, etc.). This type of internal monitoring is called *in vivo monitoring*. The other type of internal contamination monitoring uses some sample from the person to determine the presence of contamination. Methods may include urinalysis, fecal analysis, blood sampling and others. These methods are called *in vitro monitoring*.

In some cases, the presence of contamination on a worker will be assumed based on the work situation. The following list provides some examples of work situations that may result in personnel contamination.

- Exposure of the worker to known contaminated liquids
- Exposure of the worker to airborne contamination without proper respiratory protection.
- Improper work practices within removable contamination areas such as:
 - Improper removal of protective clothing or devices
 - Improper work practices with contaminated materials
 - Failure to follow radiological control requirements set for work being performed
 - Unknowingly working with material discovered to be contaminated.

2.14.01 List the three factors which determine the actions taken in decontamination of personnel.

BASIC FACTORS AFFECTING DECONTAMINATION

Once the RCT determines the worker is contaminated, the actions taken will be controlled by three basic radiological control factors. These factors include:

- Physical condition of the worker
- Location of the contamination on the worker
- Activity of the nuclide(s) present.

Primary consideration should be given to the physical condition of the worker. All actions taken by the RCT will be based on the workers physical condition. The major concern should be whether or not the worker has a serious injury. When a worker sustains a serious injury, the primary concern is the first aid or assistance the worker needs. When a worker sustains an injury, the extent of the injury needs to be determined. Conditions that should be investigated include open/puncture wounds, bruises, sprains, strains and fractures.

Once the physical condition of the worker has been identified, the location of the contamination needs to be determined. Questions requiring particular attention to answer include:

- Is contamination localized on general skin surface?
- Is contamination located on or near a body orifice?
- Is contamination located near a break in the skin?

- Is there a skin condition present in the vicinity of the contamination?
- Is the contamination on the clothing?

Finally, the amount and type of contamination needs to be determined. This will include a determination of the type of activity (alpha, beta or gamma) and saving some type of sample for laboratory analysis.

2.14.02 *List the preliminary actions and notifications required by the RCT for an individual suspected to be contaminated.*

(Insert site specific material here)

When an RCT is notified of a contaminated or potentially contaminated individual, the individual should be told to remain where they are and the following actions should be accomplished.

Obtain Instruments and Proceed To Location: The RCT should obtain the necessary instrumentation and proceed to the location of the individual with suspected contamination.

Assess Conditions: Arriving at the location, the RCT should make a quick assessment of the condition of the individual and the possibility spreading contamination. If injury is evident, the RCT must immediately notify, or designate someone to notify, the Radiological Control supervisor. If the individual is not injured, a preliminary survey will give the RCT a quick indication of the extent and locations of contamination that may be present. This quick assessment is to determine the immediate course of action and whether additional help is needed or an emergency must be declared.

While performing the assessment survey, the RCT may question the individual to gain information regarding the event that may have caused the contamination. The RCT may elect to notify the Radiological Control supervisor to ask for additional support if, in the judgement of the RCT, the support is needed. For events where there is cause to believe an internal deposition may have occurred or there is extensive contamination, a second RCT may necessary to record readings and to take and count smears (including nose blows or nasal smears). Another example of when an RCT could ask for additional support would be if there were indications that contamination control had been lost in an area frequented by other workers. A second RCT might be needed to ensure immediate posting, traffic control, and to investigate the radiological conditions.

High levels of contamination found on the skin or clothing during the preliminary survey should be removed immediately to reduce dose. Securely bag and retain removed contamination for analysis by dosimetry. Actions for lower levels of

confirmed contamination on skin or clothing may proceed in a more methodical manner as described below.

Perform A Personnel Survey: After the quick assessment survey, a detailed whole body survey should be performed of the entire exposed surface area (protective clothing if worn, 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

Use the following guidelines for the survey:

1. Verify that the instrument is in service (e.g., turn the monitor on, check the battery and source response) set it to the proper scale so that the audio output can be heard during the survey.

The instrument must have also passed a daily source check, and have a calibration date that has not expired.

2. Hold the probe less than 1/2 inch from the surface being surveyed for beta and gamma contamination, and approximately 1/4 inch for alpha contamination. Do not touch the probe to the area being surveyed to preclude contaminating the probe.
3. Move the probe slowly over the surface (approximately 2 inches per second).
4. If the count rate increases during the survey, pause for 5 to 10 seconds over the area to provide adequate time for instrument response.
5. If the count rate increases to a value greater than a pre-established contamination limit or the instrument alarms then the presence of contamination is confirmed. If confirmed, control, decontaminate and/or notify radiological control personnel (while remaining in the area).
6. The whole body survey should take several minutes. Do not hurry the survey. Take all the time necessary to complete the survey.

Using portable or semi-portable count rate type instruments, an individual may receive an unconditional personnel survey release if contamination is not detected while performing an entire body survey.

Notify Appropriate Personnel: If extensive whole body contamination is found or facial contamination is present, Radiological Control and medical personnel should be notified.

Control Contamination: 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:

1. Removing and bagging shoes and/or covering feet with plastic shoe covers/booties.
2. Covering the hands of the individual with gloves, preferably "Surgical" gloves.
3. Donning a clean set of Anti-C's over contaminated clothes or merely wrapping the individual with any covering.

2.14.03 *List the actions to be taken by the RCT when contamination of clothing is confirmed.*

CONTAMINATED CLOTHING

(Insert site specific material here)

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. 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. At a minimum, the following should be accomplished.

Control Contamination: 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.

Remove Clothing: 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.

Resurvey the Individual: Perform a personnel whole body survey after removal of contaminated clothing to determine that the individual is not recontaminated.

1. If contamination persists consider moving to a decontamination facility.
2. Assess potential for internal deposition (airborne, puncture) by surveying outside and inside of masks, surveying facial area, and taking mouth or nasal smears.

2.14.04 List the actions to be taken by the RCT when skin contamination is confirmed.

SKIN DECONTAMINATION

(Insert site specific material here)

When the skin of an individual is found contaminated, follow the specified procedures for decontamination. Stop the decontamination effort if the skin becomes irritated or the individual complains of discomfort. At a minimum, the following should be accomplished.

Remove High Levels of Contamination: Hot particles and high levels of contamination should be removed as soon as possible. The time spent to determine the activity and area of contamination should be minimized when high doses are possible.

Notify Radiological Control: Notify Radiological Control and other personnel as may be needed for dose assessment and decontamination.

Decontaminate if Appropriate: Determine the condition of the skin (cuts, sores, abrasions, irritations, etc.) and decontaminate if appropriate. 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.

Whole skin can be decontaminated by wiping with moist towelettes, 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.

Retain particles or other samples of contamination for analysis and dose assessment by Dosimetry.

Assess the Possibility of Internal Contamination: Assess potential for internal deposition (airborne, puncture) by surveying outside and inside of masks, surveying facial area, and taking mouth or nasal smears.

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 an estimate of the skin area and location affected and the activity involved. In addition, a description of the decontamination process including levels and iterations is also required.

2.14.05	<i>List the steps for using decontamination reagents to decontaminate personnel.</i>
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DECONTAMINATION REAGENTS

(Insert site specific material here)

Generally the following applies:

- Soaps and detergents emulsify and dissolve contamination and are frequently all that are needed for decontamination of skin. Decon towelettes are also used for minor decontaminating. The first attempts for decontaminating should always begin with the least irritating agent (e.g. soap and water) before proceeding to stronger techniques. Sweating may also be used to dislodge contamination by applying gloves, wraps, or warm baths.
- Sticky tapes may also be used but the potential for irritating the skin must be kept in mind. It is a common mistake to under-estimate the potential for skin irritation until too late. Particular care should be taken on the more sensitive and thin skin areas. At times, if the skin becomes irritated, decontamination may have to wait until the skin heals before proceeding with decontamination.
- 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.
- Stronger chemical techniques such as those using Potassium Permanganate (KMnO_4), Sodium Bisulfite (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.

SUMMARY

In this lesson we have covered the basic principles of personnel decontamination. Our main subjects are the actions taken in the event of potential personnel contamination, notifications required in the event of personnel injury, proper methods for identification and location of contamination, proper action to be taken once contamination has been confirmed and the approved methods for decontamination of personnel. Also discussed were the types of reagents utilized for personnel decontamination, and the precautions associated with each.

Course Title: Radiological Control Technician
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.

INTRODUCTION

"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."

References:

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

2.15.01 *List the proper steps for the treatment of minor injuries occurring in various radiological areas.*

MINOR INJURIES OCCURRING IN RADIOLOGICAL AREAS

Render first aid as needed.

Survey for contamination. The survey should include clothing, exposed skin, and any wounds. RCTs are responsible for determining whether wounds are contaminated, and to then advise Medical.

Decontamination is then performed as necessary. 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.

Inform Medical of the facts regarding injured's name and condition, location, and degree of contamination so that appropriate treatment may be administered.

Get to Medical Aid. If the injury is minor and the person is not contaminated, someone should escort the person to the nearest First Aid Station for treatment. If the injury is minor and the person is contaminated, the affected area should be covered, and they should be taken to the nearest personnel decon room or emergency decon station, and medical assistance should be requested at that location. Depending on the minor injury and local procedures, activation of an emergency response may be appropriate which would provide medical aid.

2.15.02 *List the requirements for responding to major injuries or illnesses in radiological areas.*

MAJOR INJURIES OCCURRING IN RADIOLOGICAL AREAS

If first to arrive on the scene, administer first aid to the injured. (As always, first aid should be administered only to the extent that an individual is trained and qualified to perform.) 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 the rescuer's health and safety.

Contamination levels would rarely be the cause for immediately evacuating, or delaying first aid to, a seriously injured person from an area **prior** to first aid.

- A contaminated live person is, in every case, preferable to a clean deceased person.
- 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.

Airborne radioactivity would rarely be the cause for immediately evacuating, or delaying first aid to, a seriously injured person from an area **prior** to first aid.

- Remember that a live patient with some internal contamination is always preferable to a deceased person with no internal contamination.

Radiation levels **could** require evacuation to be the first consideration. Consideration must be given to both the injured and the rescuer(s) in this instance. 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.

- This is a judgment 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.

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.

Survey the injured person(s). This should include the clothing, exposed skin, and any wounds. 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.

Assist Medical personnel with treatment, transportation, and decontamination. For a seriously injured and contaminated person, transportation would be by ambulance. For transport of contaminated person(s), the RCT would accompany the injured in the ambulance. Necessary measures should be taken to reduce or eliminate the spread of contamination on the way. 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.

Control movement of personnel between rooms at the medical facility specific to prevent the spread of contamination.

Provide containers and instruct patients regarding the collection of bioassay samples. Collect specimens of any blood, excised tissue, etc.

Survey all clothing, equipment and instruments used in the medical facility and transport vehicle. Recommend decontamination or disposal of items as necessary. Some typical problems and concerns arise in hospital situations. Portable X-ray machines, used extensively in emergency room settings, cause a problem if being brought into a room with a contaminated patient. As soon as the X-ray has been taken, the hospital staff will usually want to remove the machine from the room ASAP. Waste materials, contaminated materials, radioactive materials or particles, etc. removed from the patient may begin to pose a radiation hazard of their own if allowed to concentrate or remain in the immediate vicinity of the patient and treatment personnel. Accumulating radioactive material in the treatment area can also cause problems with monitoring for dose rates and contamination levels because of the increased background in the area.

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.*

INTERFACE OF RCT AND MEDICAL PERSONNEL

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.

The RCT must be careful **not** to make medical decisions or judgments that he/she is not qualified to make. However, the RCT **will** be primarily responsible for decisions involving radiological concerns.

The RCT should advise medical personnel of radiological conditions and precautions and make decisions concerning the radiological protection of the personnel on the scene.

2.15.04 *List the requirements for treatment and transport of contaminated injured personnel at your facility.*

REQUIREMENTS FOR THE TREATMENT AND TRANSPORT OF CONTAMINATED INJURED PERSONNEL

(Insert site specific material here.)

The following is typical of good Health Physics practices.

If the RCT is the first on the scene and there are injured contaminated personnel, the injuries always take precedence over contamination control. The RCT should only administer first aid that they are trained to perform. The RCT should get help as quickly as possible.

When help arrives, the RCT should assist medical personnel. If the contaminated individual has to be transported to the plant hospital, an RCT usually accompanies the injured person to the area. Prior to transporting, preliminary cleanup of transferable contaminants are to be done to the extent that the patient's injuries permit. If it is not possible to do a preliminary cleanup, wrap the patient in a sheet or blanket to limit the spread of contamination.

Sometimes the injury may need a more extensive evaluation and the individual may have to be transported to an area hospital. The individual should have been stabilized and if possible, contaminated clothing removed and skin decontaminated prior to transporting. If this is not possible the RCT, or other Health Physics representative, usually accompanies the individual to the hospital.

After the needs of the contaminated/injured person have been met, all areas and items that they came in contact with will have to be surveyed for contamination. Other RCT's are typically needed to assist in these situations.

The RCT is responsible for documenting all pertinent information about the incident and results of the surveys taken. The medical staff may be able to survey for contamination, but the RCT still needs to survey and complete the documentation. The RCT should make sure all documentation is thorough and accurate for legal reasons.

SUMMARY

It is imperative that the RCT be prepared to respond in the case of injuries or illnesses occurring in radiological areas. In cases of minor injuries, the primary concern will normally be the removal of contamination and preventing the spread of it. However, in the event of major injuries involving large doses of radiation or contamination patients, first aid and life saving measures will normally take precedent, even at the expense of routine contamination control measures.

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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

INTRODUCTION

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 are accurate and appropriate for the source of radiation. This lesson contains information about widely used portable radiation survey instruments.

Many factors can affect how well the measurement reflects the actual conditions, such as:

- Selection of the appropriate instrument based on type and energy of radiation, radiation intensity, and other factors.
- Correct operation of the instrument based on the instrument operating characteristics and limitations.
- Calibration of the instrument to a known radiation field similar in type, energy and intensity to the radiation field to be measured.
- Other radiological and non-radiological factors that affect the instrument response, such as RF fields, radioactive gases, mixed radiation fields, humidity and temperature.

References:

1. Radiation Detection and Measurement, Glenn F. Knoll.
2. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5th ed.; Pacific Radiation Corporation; 2008.
3. Operational Health Physics, Harold J. Moe.
4. ANSI N323A.

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.

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.

FACTORS AFFECTING INSTRUMENT SELECTION

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

- **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, mR/hr, rem/hr, mrem/hr, etc., rather than counts per minute, etc.

- **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.

- **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 mg/cm^2 , see lesson 1.07.10).

- **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).

- **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.

- **Environmental Factors**

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

- **Procedures**

If all else fails, read the instructions!

Preoperational 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.

- **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.

- **Calibration Sticker**

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

- **Battery**

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

- **Zero**

Perform a zero adjustment for the meter needle, if applicable (e.g. for ion chambers).

- **Source Check**

Perform a source response check as required by the procedures.

Instrument Selection General Principles

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.

There are general principles which apply to the specific instruments described in the following sections.

- **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

- **Instrument 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.

- **Detector Shielding**

Large amounts of shielding are not practical with a portable instrument, but some probes incorporate a small amount of shielding to reduce the background. Many external radiation survey instruments incorporate a sliding "beta shield". Note that this also shields low energy gammas.

- **Detector Window**

External radiation instruments generally have windows that are about as thick as human skin (7 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.

- **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.

- **Operator Adjustable Controls**

Portable instruments generally have a battery check.

Ion chambers generally have a zero adjustment.

- **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.

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. The effective center can be thought of as the point in the detector where the measurement of the radiation intensity is taken. 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. Therefore, the reading "taken" at the effective center represents the rate value in all portions of the detector. If the radiation field over the whole detector is not uniform, the exposure rate will not be uniform over the entire detector volume. 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 appropriate.

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*

EBERLINE RO-2 and RO-3

The Eberline RO-2, RO-3 series of instruments are portable, air-vented ion chamber instruments used to detect and measure gamma, X-ray, and beta radiation. Technical specifications for the RO-3 are similar to the RO-2.

Detector Type

The ion chamber is a phenolic, or plastic cylinder of 3 in. diameter and 12.7in³ (208cm³) volume, with one end covered by a Mylar window. The fill gas is air, vented to atmosphere through a desiccant pack.

The ion chamber detector is closer to tissue-equivalent than most types, allowing the instrument to assess the exposure rate to human tissue. 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. "Tissue equivalent" means that the detector responds the same as human soft tissue. No detector is perfectly tissue equivalent, but a well designed ion chamber is close enough for most work.

Although the detector is not as sensitive as a GM, it is the detector of choice for assessing exposure because of its close correlation to the energy deposited in human tissue by radiation.

The RO-2 series instruments are operated in the current mode, which is the mode that averages the individual pulse heights per unit time. Individual pulse information is lost; therefore, the electrical signal will not supply information about the type and energy of the individual radiation interactions. However, small pulses, which would be lost in the pulse mode, are averaged along with the other interactions.

Instrument Operating Ranges

The instrument range of the Model RO-2 is 0 - 5000 mR/hr. The readings are expressed in roentgen, 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

Detector Shielding

The sliding beta shield is made of phenolic as follows:

- RO-2 shield: $400\text{mg}/\text{cm}^2$ (1/8 in. thick) mounted on the 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 window. The detector wall is $200\text{ mg}/\text{cm}^2$ and the 0.13 cm aluminum case is about $345\text{ mg}/\text{cm}^2$.

Detector Window

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: $7\text{ mg}/\text{cm}^2$ total; two Mylar windows $3.5\text{mg}/\text{cm}^2$ (1 mil) each.
- RO-3 window: $3.5\text{ mg}/\text{cm}^2$ total; one window of 1 mil Mylar.

Types of Radiation Detected/Measured

The RO-2 instrument is designed to measure gamma, X-ray, and beta radiation but will respond to (not measure) neutron radiation. 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.

The RO-2 measures photon radiation within $\pm 20\%$ for photon energies from 12-keV to 7MeV (beta shield open). The minimum energy increases to 25keV if the shield is closed, and to about 40keV through the side of the instrument. Because of the thinner window, the RO-3 measures photons from 8-keV.

The RO-2 measures beta radiation $>70\text{keV}$ with the beta shield open. A beta correction factor may be appropriate in some situations.

Operator-Adjustable Controls

RO-2 range switch with OFF, ZERO, and BATT checking positions.

ZERO position works in conjunction with ZERO knob to electronically zero the meter. BAT1 and BAT2 positions check the two batteries used to power the instrument circuitry.

Markings for Detector Effective Center

The Effective Center markings on the RO-2 are the "dimples" or depressions on the sides and front of the instrument case.

Specific Limitations\Characteristics

The response time for the RO-2 series of instruments is 5 seconds to reach 90% of the full value.

High humidity or moisture can cause leakage currents in the detector and cause erratic meter readings. The detector is vented through a silica gel desiccant, or drying medium, contained in a plastic box. The desiccant can become saturated and will need replacement if the crystals start to turn clear or pink instead of the normal blue color.

The detector is vented to atmosphere; therefore, any change in atmospheric density changes the air density in the detector. An increase in atmospheric pressure will cause an increase in air density in the detector and cause a higher response. If the RO2 is calibrated in Los Alamos (7000 ft) and then used at sea level, the response will be 30% high. 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.

Because the detector is vented to atmosphere, radioactive gases could enter the detector and cause a reading.

BICRON RSO-50 AND RSO-500 INSTRUMENTS

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. The Bicron RSO series of instruments are very similar in design and construction to the Eberline RO-2 series of instruments.

Detector Type (identical for both models)

- Operated as an ionization chamber.

- A phenolic, or plastic, cylinder of 3 in. diameter and 12.7 in³ (208 cm³) volume with one end open but covered by a Mylar window.
- Fill gas - air (vented to atmosphere through a silica gel desiccant pack).

The Bicron RSO series instruments are operated in the current mode, or the mode that averages the individual pulse heights per unit time.

Instrument Operating Range

The instrument ranges of the two models are as follows:

RSO-50 Ranges	RSO-500 Ranges
0-50 mR/hr	0-0.5 R/hr
0-500 mR/hr	0-5 R/hr
0-5 R/hr	0-50 R/hr
0-50 R/hr	0-500 R/hr

Detector Shielding

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 window. Detector wall is 200 mg/cm² and the 0.13 cm aluminum case is about 345 mg/cm.

Detector Window

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.

- RSO windows - 7 mg/cm² total, both windows are Mylar of 5 mg/cm² each.

The sliding beta shield is made of phenolic and the density-thickness value is the same for both models.

- RSO shield - 400 mg/cm² (1/8 in. thick) and is mounted externally on the case.

Types of Radiation Detected/Measured

The Bicron RSO series of instruments are designed to measure gamma, X-ray and beta radiation but will detect (not measure) fast neutron radiation. The instruments will read

approximately 10%, in mR/hr, of the true neutron field, in mrem/hr. 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. The energy response of the two models is identical. Both models measure 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. Both models measure beta radiation >70 keV.

Operator-Adjustable Controls

RSO-500 range switch with OFF, ZERO, and BATT positions.

- Switch ranges labeled as 0.5, 5, 50, and 500 R/hr.
- ZERO position works in conjunction with ZERO knob to electronically zero the meter.
- BAT position checks the two batteries used to power the instrument circuitry and detector bias.
- OFF position turns the instrument off.

RSO-50 range switch is the same but is labeled 50 and 500 mR/hr and 5 and 50 R/hr.

Markings for Detector Effective Center

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. 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 displayed value may need to be corrected.

Specific Limitations/Characteristics

The response time varies between the two models of Bicron instruments available.

RSO-500 - approximately 10 sec from 0-90% of the final reading.

RSO-50 - approximately 5 sec from 0-90% of the final reading.

Correction factors may be needed when the radiation field is not uniform over the entire detector. High humidity or moisture can cause leakage currents in the detector and cause erratic meter readings.

- The detector is vented through a desiccant, or drying medium, contained in a plastic box.
- The desiccant can become saturated and will need replacement if the crystals start to turn clear or pink.

Like the Eberline RO-2, the detector is vented to atmosphere; therefore, any change in atmospheric density changes the air density in the detector.

- An increase in temperature will lower the air density in the detector and cause a lower response.
- An increase in atmospheric pressure will cause an increase in air density in the detector and cause a higher response.
- Tables are provided in the technical manuals for correcting the instrument response due to changes in pressure or temperature
- 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.

Because the detector is vented to atmosphere, radioactive gases can enter the detector and cause a reading.

VICTOREEN MODEL 450B

The Victoreen 450B is a portable, general purpose, ion chamber survey instrument which uses microprocessor and LCD (liquid crystal display) technology.

Detector Type

Operated as an ionization chamber. A Bakelite, or plastic, cylinder of 200 cm³ volume with one end open but covered by a Mylar window. The fill gas is air (vented to atmosphere through a desiccant pack). The ion chamber detector is designed as tissue-equivalent, allowing the instrument to accurately assess the exposure rate to human tissue. The Victoreen 450B is operated in the current mode as are most ion chambers.

Instrument Operating Ranges

- Overall range is 0-50 R/hr.

The instrument is autoranging, or automatically changes scales as required for the instrument reading, and has the following scales:

450B Scales
0-5 mR/hr
0-50 mR/hr
0-500 mR/hr
0-5 R/hr
0-50 R/hr

Detector Shielding

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. The detector wall is 200 mg/cm². The sliding beta shield is made of Bakelite, which is a type of plastic and the density-thickness value is 440 mg/cm².

Detector Window

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/cm².

Type of Radiation Detected/Measured

The 450B instrument is designed to measure gamma, X-ray, beta and alpha radiation but will detect (not measure) fast neutron radiation. The instruments will read approximately 10%, in mR/hr, of the true neutron field, in mrem/hr.

Energy response. Photon energy response ($\pm 20\%$) is about 20 keV for slide open, 40 keV for slide closed, and 50 keV from the side. Beta energies >32 keV can be measure. 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.

Operator-Adjustable Controls

Only three external controls are available on the 450B: the ON/OFF switch, the MODE switch and the meter light button. The Mode switch is used during calibration and is not enabled for operator use. The ON/OFF switch turns the instrument on and off. The instrument is autoranging and will change the bar graph, digital value and scale markings as appropriate for the exposure rate value.

The instrument has an "autozero" feature that eliminates any need for an external zero control. If the batteries are low, then the instrument will display a LOW BAT message. A button switch is provided in the handle for turning the meter face light on and off.

Markings for Detector Effective Center

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.

Specific Limitations/Characteristics

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:

450B Response Times	
0-5 mR/hr	8 sec
0-50 mR/hr	5 sec
0-500 mR/hr	2 sec
0-5 R/hr	2 sec
0-50 R/hr	2 sec

Geotropism, or the effect of gravity on the instrument, causes no greater than a $\pm 1\%$ of full scale change from the actual value. Correction factors must be applied when the radiation field is not uniform over the entire detector, such as for surface contamination beta dose rates. High humidity or moisture could cause leakage currents in the detector and cause erratic meter readings. The detector is vented through a desiccant, or drying medium, contained in a plastic cylinder. The desiccant could become saturated and will need replacement if the crystals start to turn clear or pink. 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. The rubber bladder minimizes the effects of high humidity environments and radioactive gases. The detector is vented to atmosphere; therefore, any change in atmospheric density changes the air density in the detector. An increase in temperature will lower the air density in the detector and cause a lower response. An increase in atmospheric pressure will cause an increase in air density in the detector and cause a higher response. The value of the changes due to temperature and pressure are similar to those of other air-vented ion chambers.

- 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*

The Eberline Teletector is an extendible, telescoping-rod instrument designed with two Geiger-Mueller (GM) detectors for the measurement of photon exposure rates and detection of beta radiation.

Detector Types

Both detectors are sealed GM tubes with halogen-quenched argon fill gas contained in an energy compensating case. Energy compensation is required in GM detectors to reduce the over response to low energy photons.

The low range detector is the largest of the two detectors and is located at the end of the detector housing. The low range detector is used for the three lowest ranges on the instrument.

The high range detector is the small cylinder in the detector housing, and is used for the upper two scales.

The GM detectors are very sensitive; however, they lack the direct correlation to energy deposited and are not as accurate as ion chamber instruments for assessing exposure rates.

The Teletector instrument is operated in the pulse mode, or the mode that counts each individual pulse. Since any ionization in a GM tube causes the same large pulse, any radiation interaction in the detector will be counted. 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.

Instrument Operating Ranges

The instrument range is 0 - 1000 R/hr.

The analog Teletector has five settings. The three lower settings utilize the large GM detector and the two upper settings utilize the smaller GM detector.

Teletector Settings
0-2 mR/hr
0-50 mR/hr
0-2 R/hr
0-50 R/hr
0-1000 R/hr

Detector Shielding

The two detectors are shielded by layers of lead and fiber to compensate for the GM over-response to low-energy photons. The high-range detector is partially shielded by the low-range detector.

Detector Window

The low-range detector has a 30mg/cm² mica window and a rubber cap to protect the window.

Types of Radiation Detected/Measured

The Eberline Teletector will measure gamma and X-ray radiation and responds to (but does not measure) beta radiation. According to the manufacturer, beta response is not accurate. Alpha response is eliminated by the thicker window and

casing. Neutron response is insignificant due to the lower probability of interaction in the small detectors.

The Teletector measures photon radiation >80 keV. Lower energy photons are attenuated in the detector window. Beta particles >160 keV can be detected but not measured.

Operator-Adjustable Controls

The only control is the range switch with OFF and B (battery check) positions.

Detector Effective Center Markings

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.

Specific Characteristics and Limitations

Response time for the instrument is approximately 1 second to 90% of full scale.

The sealed detectors do not require correction factors for temperature or pressure. The sealed detectors do not experience problems with humidity or radioactive gases entering the detector.

Audible indication is available only through the speaker jack; no internal speaker is installed.

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. The manufacturer states (on the title page of the 6112B brochure) that the Eberline Teletector will not saturate, up to 30,000 R/hr (which is larger than the maximum range).

It is easy to damage the instrument by bending the extendible tube.

EBERLINE RO-7

The RO-7 series instrument provides remote monitoring in high range beta and gamma radiation fields. The RO-7 consists of a basic digital readout instrument, three interchangeable detectors, and various interconnecting devices. 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.

Detector Types

All three detectors are air-vented ion chambers contained in a plastic-lined (phenolic) aluminum housing. The detector fill gas is air. The detector housing also contains other electronics, such as an operational amplifier and detector identification circuitry.

The three available detectors are as follows:

- The RO-7-LD is a low-range, gamma-only detector with an active volume of about 50 cm³ and dimensions of 2.5 cm diameter and 10.2 cm long.
- The RO-7-BM is a mid-range, beta/gamma detector, with beta window, that has an active volume of about 7 cm³ and dimensions of 2.5 cm diameter and 5 cm long.
- The RO-7-BH is a high-range, beta/gamma detector, with beta window, that has an active volume of about 7 cm³ and dimensions of 2.5 cm diameter and 5 cm long.

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.
The RO-7 instrument is operated in the current mode of operation.

Instrument Operating Ranges

The operating range of the instrument is dependent on the detector that is connected to the instrument.

- The range of the RO-7-LD detector is 0-2 R/hr.
- The range of the RO-7-BM detector is 0-200 R/hr.
- The range of the RO-7-BH detector is 0-20 kR/hr (20,000 R/hr).

Detector Shielding

All three detectors have a phenolic liner and aluminum housing.

Detector Window

The RO-7-BM and RO-7-BH detectors each have a 7 mg/cm² Mylar window. The Lucite cap for the beta window is 100 mg/cm².

Types of Radiation Detected/Measured

As previously mentioned, the RO-7-LD detector measures only gamma and X-ray radiation. Both beta and alpha radiation are shielded by the detector housing. The neutron radiation response is insignificant due to the small size of the detector. The actual detectors in the RO-7-BM and RO-7-BH detector assemblies are identical. Both detect and measure gamma, X-ray and beta radiation. Alpha response is eliminated by the 7 mg/cm² window (same density thickness as the outer layer of skin). Neutron radiation response is even smaller than the RO-7-LD due to the smaller detector volume.

The energy response for the three detectors is as follows:

The RO-7-LD responds to photon radiation between 50 keV and 1.3 MeV ($\pm 20\%$). 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.

- Lucite cover off - 10 keV to 1.3 MeV ($\pm 20\%$)
- Lucite over on - 25 keV to 1.3 MeV ($\pm 20\%$)
- Shield on, from the side - 50 keV to 1.3 MeV ($\pm 20\%$)
- The beta response for the RO-7-BM and RO-7-BH detectors is for beta energies >70 keV.

Operator-Adjustable Controls

The ON/OFF switch is the only range control because the instrument identifies the detector model and adjusts the readout accordingly. A low battery condition is indicated by a "colon" under the battery mark on the meter. The ZERO knob will zero the LCD readout. A meter face light is turned on/off by the small switch in front of the pistol grip.

Detector Effective Center

No markings are provided for the detector effective center.

Specific Limitations/Characteristics

The response time of the basic instrument is 2.5 seconds to 90% of the final reading. The correction factor for the true beta measurement is 1.5 as recommended by the manufacturer.

Since the detector is air-vented, atmospheric temperature and pressure changes affect the instrument reading. The instrument response will remain within $\pm 10\%$ for the temperature range of -20 to 160 °F. A correction table is available in the technical manual for pressure changes. 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. Each detector has associated electronics designed for that particular range. Overranging a detector may cause damage to the detector electronics. 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.

Interconnecting devices from the detector to the instrument that are available from the manufacturer are the:

- 15 ft flexible cable
- 60 ft flexible cable
- 2 ft rigid extension
- 5 ft rigid extension
- Stainless-steel underwater housing with 60 ft of cable.

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*

NEUTRON DETECTORS

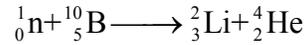
EBERLINE NRD NEUTRON SPHERE

The Eberline Neutron Rem Detector (NRD) sphere is a portable instrument for the detection and measurement of the dose rate from neutron radiation.

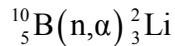
Detector Types

The detector is the Eberline NRD (Neutron Rem Detector) sphere, which may be connected to a PNR-4 (Portable Neutron Rem) or to an ESP (Eberline Smart Portable) instrument by a coaxial cable. The NRD sphere is a 9 inch diameter, cadmium loaded, polyethylene sphere with a BF_3 proportional tube in the center of the sphere. The BF_3 (boron trifluoride) detector design allows the detection of

neutrons only, and the rejection of other radiation. The thermal neutron capture reaction with the ^{10}B results in gas ionization pulses caused by the alpha particle from the reaction:



or



The 9 inch diameter polyethylene sphere is used to moderate the neutrons. The polyethylene has a high percentage of hydrogen which thermalizes the fast and intermediate energy neutrons. Those neutrons that are thermalized in the sphere can be detected in the BF_3 tube. The cadmium loading is a thin sheet of cadmium placed at a radius of about 7 cm inside the polyethylene sphere to help reduce the over response to lower energy neutrons.

Instrument Operating Ranges

When the NRD is connected to the PNR-4 readout, there are two needles. One needle covers the range up to 50 mrem/hr; above 50 mrem/hr, the second needle takes over and covers the range up to 5000 mrem/hr. The NRD may also be connected to an Eberline Smart Portable, ESP, which is discussed in lesson 2.17.

Types of Radiation Detected/Measured

Neutrons are measured. Alpha and beta radiation are not detected because they do not penetrate the detector shielding. Gamma radiation passes through the detector shielding but is rejected by the BF_3 proportional chamber up to 500 R/hr (dependent on high voltage setting and desired rejection level).

Since the BF_3 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. The mode of operation for the instrument is the pulse mode so that individual pulses can be discriminated and counted. Pulses from gammas are rejected. Alpha and beta particles do not penetrate the polyethylene sphere.

Energy Response

The energy response curve for the instrument shows the relative response of the instrument as compared to the theoretical dose. This instrument over-responds to intermediate energy neutrons, and under-responds to relativistic neutrons.

Operator-Adjustable Controls

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.

No markings are provided for the detector effective center as the active volume of the detector is centered in the sphere.

Specific Characteristics and Limitations

The response time depends on which decade of the scale is appropriate.

Response Times	
First Decade	12 sec
Second Decade	6 sec
Third Decade	1.5 sec
Fourth Decade	0.3 sec

The detector is a sealed pressurized cylinder and is not affected by changes in humidity, radioactive gases or changes in atmospheric density.

EBERLINE ASP-1 WITH NRD SPHERE

The Eberline ASP-1 with the NRD sphere is a microcomputer-based, analog-display, portable neutron radiation survey instrument. The detector (Eberline NRD sphere) is identical to the detector used with the PNR-4 readout packages. The mode of operation is the pulse mode.

Instrument Operating Ranges

The overall range is 0-100 rem/hr and has a useable range of 1 mrem/hr - 60 rem/hr.

ASP-1 Ranges
0-1 mrem/hr
0-10 mrem/hr

0-100 mrem/hr
0-1,000 mrem/hr
0-10,000 mrem/hr
0-100,000 mrem/hr

Detector shielding is the same as previously mentioned for the NRD sphere. The energy response is the same as previously mentioned for the NRD sphere.

Operator-Adjustable Controls

The OFF/BAT/HV/range switch has the following functions:

- The OFF position turns the instrument off.
- The BAT position checks the instrument battery power supply.
- 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.

The range markings are X1, X10, X100, X1K, X10K, and X100K with a meter scale of 0-1.0.

The INTEGRATE/FAST/SLOW switch is a three position toggle switch with the following functions:

- 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.
- In the FAST position, the response time selected by the microcomputer is for typical survey work.
- In the SLOW position, the response is slower but with greater accuracy than the FAST position.

The LIGHT/RESET switch is a three-position, spring-loaded toggle switch with the following functions:

- The LIGHT position illuminates the meter face
- The RESET position will zero the meter reading for the current mode (INTEGRATE/FAST/SLOW) setting of the instrument.

The RESET switch will cause the "standard current" value to be displayed if held for 5 seconds while in the FAST or SLOW mode. The SPEAKER is a two-position toggle switch for turning the external speaker on and off. Acoustic (airline-type) head phones can be plugged into the speaker cover on the top of the instrument. As previously mentioned, the NRD sphere has no effective center markings.

Specific Limitations/Characteristics

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. In the FAST position, the instrument response time varies between one and ten seconds. In the SLOW position, the instrument response time will vary up to a maximum of 29 seconds. No correction factors are required to correct the displayed value. The sealed detector is not affected by changes in atmospheric density, humidity or radioactive gases. The instrument has a microcomputer controlled "overrange" indication. When the radiation rate exceeds the useful range of the detector, the computer will cause an overrange alarm. When the instrument alarms, the meter needle will sweep back and forth and an interrupted tone will sweep in the speaker.

SUMMARY

This lesson has covered the specifications, features and limitations for the portable radiation survey instruments that may frequently be used by the RCT. This knowledge should be used to properly select and operate the instruments to ensure that the data obtained is accurate and appropriate. The appropriate and accurate data is then used to properly assign external exposure controls.

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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:
 - a. Detector type
 - b. Detector shielding and window
 - c. Types of radiation detected/measured
 - d. Energy response for measured radiation
 - e. Specific limitations/characteristics.
- 2.17.03 Describe the following features and specifications for commonly used count rate instruments used at your site.
 - a. Types of detectors available for use
 - b. Operator-adjustable controls
 - c. Specific limitations/characteristics.
- 2.17.04 Describe the following features and specifications for commonly used personnel contamination monitors at your site.
 - a. Detector type
 - b. Detector shielding and housing
 - c. Types of radiation detected/measured
 - d. Scaler type uses
 - e. Scaler operator-adjustable controls
 - f. Specific procedures for source checks
 - g. Specific procedures for sample counts.
- 2.17.05 Describe the following features and specifications for commonly used contamination monitors used at your site (tool, bag, laundry monitors).
 - a. Detector type
 - b. Detector shielding and window
 - c. Types of radiation detected/measured
 - d. Energy response for measured radiation
 - e. Specific limitations/characteristics.

INTRODUCTION

This lesson covers contamination monitoring instruments in relation to types used, purpose for, radiation monitored, operational requirements, and specific limitations and characteristics. The RCT uses information from these monitoring instruments to identify and assess the hazards presented by contamination and establish protective requirements for work performed in contaminated areas.

References:

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

NOTE: *Text is provided for some commonly used contamination monitoring instruments (except those included by Objective 5). The site may adjust text as necessary for instruments used at the site. Text added for specific instruments used at the site must, at a minimum, cover the material required by the objective.*

GENERAL DISCUSSION

Measurements using portable contamination monitoring (count rate) instruments provide the basis for assignment of practical contamination and internal exposure controls. To establish the proper controls, the contamination measurements must be an accurate representation of the actual conditions. 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. 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.

Many factors can affect how well the measurement reflects the actual conditions, such as:

- Selection of the appropriate instrument based on type and energy of radiation, radiation intensity, and other factors
- Correct operation of the instrument based on the instrument operating characteristics and limitations
- Calibration of the instrument to a known radiation field similar in type, energy and intensity to the radiation field to be measured
- Other radiological and non-radiological factors that affect the instrument response, such as radioactive gases, mixed radiation fields, humidity and temperature.

2.17.01 *List the factors which affects an RCT's selection of a portable contamination monitoring instrument.*

FACTORS AFFECTING INSTRUMENT SELECTION

The selection of the proper instrument is critical to ensure the data obtained is accurate and appropriate. Instrument selection is based on the characteristics and specifications for that instrument as compared to the required measurements.

Several factors should be considered when selecting the instrument.

- The type of radiation to be measured
- The energy of the radiation to be measured
- The intensity of the radiation (dose rate or activity levels)
- Interference from a mixed radiation field
- Background radiation conditions
- Environmental factors, such as radioactive gases or temperature, affecting instrument response
- Procedural requirements.

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.

- 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:*
- a. Detector type*
 - b. Detector shielding and window*
 - c. Types of radiation detected/measured*
 - d. Energy response for measured radiation*
 - e. Specific limitations/characteristics..*

COUNT RATE METER HAND PROBES

EBERLINE MODEL HP-210 AND VICTOREEN MODEL 110C

Models like the Eberline Model HP-210 or Victoreen Model 110C hand probes are sensitive beta detectors using a thin window "pancake" Geiger-Mueller (GM) detector. These detectors are designed for contamination surveys of personnel, table tops, floors, equipment, etc.

Detector responds to alpha, beta, gamma and X-ray radiation of minimum energies.

- 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.
- 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).
- 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.

GM tube has mica window of 1.4 to 2.0 mg/cm² density

Gamma sensitivity is approximately 3,600 counts per minute (cpm) per mR/hr for Cs-137.

Available with either high-density tungsten or aluminum housings

- HP-210AL - aluminum housing with a low shielding factor for low background use
- HP-210T - tungsten shield covering the top and sides of the detector allows use in high background area
- Victoreen 110C - aluminum housing with a low shielding factor for low background use.

Victoreen 110C series hand probes are almost identical to the Eberline model HP-210AL.

Detector Type

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. The shielded hand probe contains the GM detector which has the mica window protected by a wire or stainless-steel etched screen. The fill gas in the GM tube is halogen-quenched argon.

The operating voltage for the GM detector is $900V \pm 50V$. The detector has a 50 μ s 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.

Detector Window and Shielding

The thin detector window is 1.4-2.0 mg/cm² mica and is protected by the screen which is 79% open. Mica windows must be used instead of Mylar, because the Mylar will react with the halogen quench gas. The window has an effective surface area of 2.4 inch² (15.5 cm²).

Efficiencies for the detector are dependent on the type and energy of the radiation. The detector is designed, calibrated and used to measure beta radiation

22% for Cs-137
 16% for Co-60
 32% for Sr-90 -Y-90
 15% for Tc-99
 6% for C-14

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). 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%.

Specific Limitations and Characteristics

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.

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 inch and at a speed of about 1 inch per second.

The mica window is extremely fragile and sufficient care must be taken to prevent any punctures which will ruin the detector.

The detector probe is not calibrated for alpha radiation; however, it may be used for indication of alpha emission from contamination, if used properly.

VICTOREEN MODEL 489-4 DETECTOR PROBE (THYAC)

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.

Detector Type

The detector is a sealed Geiger-Mueller (GM) cylindrical detector. The shielded probe contains the cylindrical GM tube which has a stainless steel wall surrounding the entire detector volume. The fill gas in the GM tube is halogen-quenched argon. The operating voltage for the GM detector is $900V \pm 50V$.

Detector Window and Shielding

The detector "window" is the 30 mg/cm² stainless steel wall of the detector. Shielding provided by a 360E sliding steel shield.

The GM detector will detect any radiation that interacts within the sensitive volume of the detector.

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. 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. Alpha particles can not be detected because all alpha particles would be stopped in the detector wall.

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.

Specific Limitations and Characteristics

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. When used with a count rate meter, the meter reading (cpm) is converted to a dpm value by multiplying by thirty ($\text{dpm} = \text{cpm} \times 30$). The detector probe is not calibrated and is not recommended for measurement of beta radiation due to the thickness of the detector wall.

EBERLINE MODEL AC-3 ALPHA HAND PROBE

The Model AC-3 is an alpha scintillation detector used to identify alpha-emitting contamination.

Detector Type

Scintillation detector using ZnS (Ag) powder embedded in tape. Active detector area is 9.1 inch² (59 cm²) within a 5 3/4 x 2 inch sampling area. Low gamma sensitivity.

Detector Window and Shielding

Window is 1.5 mg/cm² aluminized plastic film. Total probe assembly is 11 1/2 inches long x 2 3/4 inches wide x 3 1/4 inches. Clear plastic probe cover is supplied for protecting the detector window. Weight of probe is 1 pound 6 ounces.

Efficiency

From a 1-inch diameter source or from 50 cm² of a large-area distributed Pu-239 source, 2 pi geometry. Minimum efficiency is 28%. Typical efficiency is 31%. Sensitivity to Pu-239 source is typically 2×10^7 cpm per microcurie/cm².

Specific Limitations and Characteristics

Probe is sensitive to gamma radiation. Not used in areas where gamma interference in mR/hr will indicate ≥ 300 cpm alpha. The mR/hr value is affixed to each instrument during routine calibration.

Detector window is very fragile. Puncture or damage to covering will cause detector to become sensitive to light.

Erratic meter movement can be due to electrical short in probe connection cable.

Detector is to be held 0.5 cm from the surface and moved at approximately 1-2 inches per second.

- 2.17.03 *Describe the following features and specifications for commonly used count rate instruments used at your site.*
- a. Types of detectors available for use*
 - b. Operator-adjustable controls*
 - c. Specific limitations/characteristics.*

COUNT RATE INSTRUMENTS**VICTOREEN MODEL 496**

Victoreen Model 496 is an analog GM count rate meter.

Used in conjunction with GM probe assemblies to measure beta and gamma radiation.

Victoreen 489-4
Victoreen 110-C
Eberline HP-210

Three operating ranges of 0-800, 0-8,000, and 0-80,000 cpm.

Response time of 10 seconds or less to 90% of the final reading.

Accuracy of $\pm 10\%$ normally.

Weight of 4 pounds.

Operation

Meter face readout of 0-800

Rotary switch for power and range functions

- Off - setting for non-operation
- Batt - initial selection for testing of battery strength, needle will identify battery strength
- x1 - establishes meter reading times 1 as the activity in cpm (0-800 range)
- x10 - identifies meter reading times 10 as the activity in cpm (0-8,000 range)
- x100 - identifies meter reading times 100 as the activity in cpm (0-80,000 range).

Volume Control Rotary Switch

Audible indication of count rate by independently controlled speaker

Functions of off and on to control speaker

Correction factors for beta/gamma cpm to dpm reading based on type of detector attached

Thyac 489-4 - meter reading x 30

Pancake probes - meter reading x 10

LUDLUM MODEL 12

Ludlum Model 12 is an analog count rate meter

Electronic circuitry has potential for use of proportional, scintillation, and GM detectors

Available in three different detector configurations

Eberline HP-210 detector - used for beta-gamma measurement

Victoreen 110C - used for beta-gamma measurement

Eberline AC-3-7 Probe - used for alpha measurement

Operating ranges of 0-500, 0-50,000, and 0-500,000 cpm

Fast-Slow toggle switch provides for meter response time selection

- Slow - response time of 22 seconds for 90% of final reading
- Fast - response time of 4 seconds for 90% of final reading.

Operation

Meter face readout of 0-500

Range multiplier selector switch is a six-position switch

1. OFF
2. BAT
3. x1,000
4. x100
5. x10
6. x1

Audio on-off switch for operation of count rate speaker

Fast-Slow toggle switch to establish response time of 4 seconds (fast) or 22 seconds (slow)

RES button provides a rapid means to reset the meter to zero

HV Test Button displays the detector voltage on the meter when depressed

Operates on two standard "D" cell batteries or rechargeable cells

Weight of 3.0 pounds, less detector and batteries

LUDLUM MODEL 3-6

Ludlum Model 3-6 is an analog survey instrument

Electronic circuitry has potential for use of proportional, scintillation, and GM detectors

Operating ranges of 0-500, 0-5,000, 0-50,000, and 0-500,000 cpm
Fast-Slow toggle switch provides for meter response time selection

- Fast - response time of 5 seconds for 90% of the final reading
- Slow - response time of 25 seconds for 90% of the final reading.

Operation

Meter face readout of 0-5,000

Range multiplier selector switch is a six-position switch

1. OFF
2. BAT
3. x 100
4. x 10
5. x 1
6. x 0.1

Audio on-off switch for operation of count rate speaker

Fast-Slow toggle switch to establish response time of 5 seconds (fast) or 25 seconds (slow)

RES button provides a rapid means to reset the meter to zero

Operates on two standard "D" cell batteries or rechargeable cells

Weight of 3.5 pounds, less detector

LUDLUM MODEL 177-2

Ludlum Model 177-2 count rate meter is placed at specific locations for personnel contamination monitoring

Electronic circuitry has potential for use of scintillation, and GM detectors

Available in conjunction with alpha, beta-gamma, and alpha-beta-gamma detection probes

Operating ranges of 0-500, 0-5,000, 0-50,000, and 0-500,000 cpm
Fast-Slow toggle switch provides for meter response time selection

- Slow - response time of 22 seconds for 90% of final reading
- Fast - response time of 2.2 seconds for 90% of final reading.

Operation

Meter face readout of 0-500

Range multiplier selector switch is a six position switch

1. OFF
2. x 1
3. x 10
4. x 100
5. x 1,000

Audible click per radiation incident volume control adjustment

Operates on 115 V AC only and does not contain battery pack

RES Button provide a rapid means to reset the meter to zero

Alarm Set Selector Switch is 11 position switch used to select a predetermined alarm threshold (0.5 to 500) at 100 cpm over background

Weight of 4.2 pounds, less detector.

- 2.17.04 *Describe the following features and specifications for commonly used personnel contamination monitors at your site.*
- a. *Detector type*
 - b. *Detector shielding and housing*
 - c. *Types of radiation detected/measured*
 - d. *Scaler type uses*
 - e. *Scaler operator-adjustable controls*
 - f. *Specific procedures for source checks*
 - g. *Specific procedures for sample counts.*

PERSONNEL CONTAMINATION MONITORS**PERSONNEL CONTAMINATION MONITOR PCM-1B**

Eberline Personnel Contamination Monitor, Model PCM-1B is a microprocessor-based radiation detection system

Performs quick indication of beta-gamma contamination, with option of alpha capabilities

PCM-1B has fifteen (15) independent gas-flow proportional detectors

Control processing unit (CPU) includes an Intel 8085 microprocessor, memory, and input-output lines

Performs two-part personnel whole body survey by performing a right side then left, personnel body survey.

Operation mode

Monitor measure and stores background values for all detectors

Checks for high background alarm levels

Checks for low or high count failures

Checks for low gas pressure conditions

Ultrasonic motion sensor detects movement of person toward monitor

Background check is suspended

Display reads - "STEP UP - INSERT RIGHT ARM"

Placement of arm in arm cavity initiates personnel monitoring routine

Display reads - "COUNTING RIGHT SIDE"

Counting continues for duration of specific counting time

If no alarm levels detected, unit beeps and displays clearance

Display reads - "RIGHT SIDE OK -- INSERT LEFT ARM"

Placement of left arm in cavity initiates monitoring

Display reads - "COUNTING LEFT SIDE"

Counting continues for duration of specific counting time

If no alarm levels detected, unit beeps and displays clearance

Display reads - "COUNT COMPLETE, YOU MAY PASS"

Display accompanied by chime and the LED extinguishes.

Alarm modes

Premature arm withdrawal

Arm withdrawn prior to preset count time completion

Alarm alert sounds

Display reads - "COUNT INCOMPLETE **RECOUNT**"

Reinsertion of arm restarts count

Contamination detection

Activity in excess of alarm levels detected in either right or left side count

Alarm alert sounds at end of count time

Appropriate display appears - "ALARM: ZONE 1 - ZONE 2 - ZONE 3," etc.

Alarm and display continue for specified alarm hold time

Alarm stops and display reads - "CONTAMINATED -- PLEASE STEP OUT."

Troubleshooting

PCM-1B message display will illuminate the trouble or diagnostic lights to identify various monitor malfunctions. Description of basic malfunction conditions listed below:

High background - Background count rate in any zone(s) has increased above selected limit.

Alarm light, high background light, sonalert, and "Channel Designation (i.e., 'Zone 1 ft): High Background" message are activated.

Area should be checked for radioactive sources and/or detector checked for dirt, moisture or radioactive contamination.

High count fail

- Alarm light, trouble light, sonalert, and channel designation message are activated.
- Count capacity in any zone has been exceeded and PM Group to be contacted for troubleshooting.

Low count fail or low sensitivity fail

- Alarm light, trouble light, sonalert, and channel designation message are activated.

May be the result of component failure or decrease/loss of decrease/loss of counting gas. Detector identified should be checked for leak in mylar. Leak in mylar can be sealed with scotch tape.

Contaminated detector

Contaminated detector light is activated along with contaminated detector message. Operation will continue with detector light on.

Detector to be checked for contamination and decon around detector performed with masslin cloth.

Loss of gas pressure

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.

If both cylinders fail (empty) the trouble light, "Bottle No. 2 Empty," and display with indicate "Failure**Out of Gas" message will be activated.

PCM-1B must not be used to monitor personnel with any trouble light illuminated. Monitor placed in "Out of Service" mode until cause corrected.

EBERLINE PM-6

Microprocessor based radiation monitor using gas-flow proportional detectors for whole body contamination scans.

Two basic types of PM-6s are typically used.

PM-6A

Uses eleven gas-flow counters to detect beta-gamma contamination.

Same basic operating characteristics as PCM-1B.

Source checked daily using beta-gamma source.

PM-6A-2

Uses fifteen gas-flow counters to detect alpha or beta-gamma contamination.

Four additional detectors used in hand pods to increase ability to detect hand contamination.

Hand and foot detectors sensitive to alpha as well as beta-gamma contamination. Source checked daily using alpha and beta-gamma sources for both hand and foot detectors. Beta-gamma source is used on body detectors.

Source checks and troubleshooting PM-6 is same as PCM-1B.

OTHER CONTAMINATION MONITORS

- 2.17.05 *Describe the following features and specifications for commonly used contamination monitors used at your site (tool, bag, laundry monitors).*
- a. *Detector type*
 - b. *Detector shielding and window*
 - c. *Types of radiation detected/measured*
 - d. *Energy response for measured radiation*
 - e. *Specific limitations/characteristics.*

(Site must add material based on other contamination monitors, such as tool, bag or laundry monitors, used at the site. Text added must cover the material required by the objective.)

SUMMARY

In this lesson, we have covered contamination monitoring instruments in relation to types used, purpose for, radiation monitored, operational requirements, and specific limitations/characteristics for use. The RCT uses this information to identify and assess the hazards presented by contamination and establish protective requirements for work performed in contaminated areas.

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 (CAMs).
- 2.18.06 Identify the physical and operating characteristics and the limitation(s) of alpha constant air monitors (CAMs).

INTRODUCTION

This lesson covers air sampling equipment in relation to types used, operational and physical characteristics, limitations, and methods of sampling. The RCT uses this information to identify and assess the hazards presented by airborne contamination and establish protective requirements for work performed in airborne contamination areas.

References:

1. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5th ed.; Pacific Radiation Corporation; 2008.
2. Operational Health Physics, Harold J. Moe.
3. ANSI N323A.
4. (Various Manufacturer Technical Manuals.)

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.*

2.18.01 *Identify the factors that affect the operator's selection of a portable air sampler.*

SELECTION FACTORS

The factors affecting the selection of portable air samplers are:

- Type of radiation emitted by airborne contaminant in question
- Physical state of airborne contaminant
- Type and duration of job being performed.

PHYSICAL AND OPERATING CHARACTERISTICS AND LIMITATIONS

2.18.02 *Identify the physical and operating characteristics and the limitation(s) of the Staplex and Radeco portable air samplers.*

STAPLEX

Operational characteristics

- Centrifugal force is the method used to induce air movement. Centrifugal force produces kinetic energy. Resultant velocity pressure converted to suction for moving sampled air
- Self-cooling - Inappropriate for long-term continuous sampling
- Variable orifice flowmeter calibrated 0-70 cfm. Flow rate sticker on side is specific for appropriate collection method. Typical flow rate(s): 7-28 cfm

Physical characteristics

- 110-V fan motor with on-off switch. Requires external power source
- 4-inch filter holder assembly with intake screen. MSA charcoal adaptor available
- Portable: 10 pounds

Limitations

- Inappropriate for long-term continuous sampling
- May create an airborne area due to exhaust
- potential "crawler" while in operation due to the high torque generated by the fan
- DO NOT use in explosive atmospheres

Methods of sampling

- Filtration
- Adsorption, if charcoal is used
- Impaction, if impactor head is installed

Placement for surveys

- Avoid creating airborne activity through stirring up dust with sampler exhaust air
- Tripods available
- May be hung on chain for optimum positioning

Annular Kinetic Impactor Head

- Inertial Collector-Head collects large airborne particles such as plutonium without collecting coexisting particles containing radon and thoron
- Principle: Air to be sampled enters annular space at rear, makes a 180-degree turn at greased planchet, and out the center tube
- Size of particles collected can be varied by adjusting slit width and air flow velocity
- Physical characteristics. - Head replaces Staplex screened intake orifice. Lightly greased planchet placed on head intake.

RADECO (H809-VI)*Operational characteristics*

- Equipped with rotameter air flow indicator. Rotameter consists of a "float" which is free to move up and down and a vertical tapered tube, which is larger at top than bottom and contains the float. Air flows up the tube causing float to rise. Height to which float rises is proportional to air flow rate
- Many different types of floats found at facilities however, rotameters are conventionally read at the highest point of maximum diameter, unless otherwise indicated. If in doubt about how to read a particular rotameter, check with supervision.
- Flow rate adjustable from 1 to 8 cfm
- 110-125 VAC

Physical characteristics

- Equipped with a two-stage turbine blower and one horsepower self-cooling universal type motor
- Sample head uses 2 in. or 47 mm particulate and iodine filters
- Instrument panel has a three-position switch - (HIGH/OFF/VARIABLE), a control knob for FLOW ADJUST, a fuse holder, and a rotameter
- Weight: 10 lbs

Limitations

- Cannot be used in explosive atmospheres
- Inappropriate for long-term continuous sampling

Methods of sampling employed

- Filtration
- Adsorption, if charcoal is used

2.18.03	Identify the physical and operating characteristics and the limitation(s) of Motor air pumps.
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MOTOR AIR PUMPS

Types of motor air pumps:

- MotoAir
- ITT
- Eberline.

These units normally used to sample for extended periods of time at low flow rates.

Operational characteristics of typical motor air pumps

- Flow rate maintained relatively constant by regulator.
- Requires 110 V power supply.

Physical characteristics of typical motor air pumps

- Sample heads used designed to accept 2 inch diameter (47 mm) media for both particulates and iodine.
- Common components are the carbon vane pump, the constant flow air regulator, and the flow meter.
- Grounded three wire power cord is provided.

Typical features - Eberline RAS-1

- Operational characteristics - Rotameter type flow meter with a flow rate range 0.5 to 3.5 cfm and power requirement 5 amps
- Physical characteristics - 'Screw in' type particulate filter holder, a 'Clamshell' type iodine filter holder, a ON/OFF power switch, and weight is 30 lb

Sampling considerations

- Filter paper must cover intake screen.
- Charcoal cartridge holder must have good seal.
- Check flow rate after turning on and before turning off.

Reading a rotameter

- Rotameter consists of a "float" which is free to move up and down, and a vertical tapered tube, which is larger at top than bottom and contains the float.
- It operates using air pressure. Air flows up the tube, causing the float to rise. Height to which float rises is proportional to air flow rate.
- Rotameters are conventionally read at the highest point of maximum diameter, unless otherwise indicated.

2.18.04 *List the steps for a preoperational checkout of a portable air sampler.*

PREOPERATIONAL CHECKOUT OF PORTABLE AIR SAMPLERS

1. Verify the air sampler has a current Calibration Sticker.
2. Physical Damage
 - Power cord in good condition
 - All gaskets in place
 - General physical condition of housing and controls.
3. Working Condition
 - Verify operating properly by checking for sound (no unusual noises), sight (no smoke, no excessive sparking from motor brushes), smell (no burning), and feel (no unusual vibration, not overly hot to touch).
 - Appropriate air flow
 - Controls on sampler are operable
 - Ensure filters and cartridges are loaded in proper orientation to air flow prior to sampling.

2.18.05 *Identify the physical and operational characteristics and the limitation(s) of beta-gamma constant air monitors (CAMs).*

BETA-GAMMA CONSTANT AIR MONITORS (CAMs)

General Characteristics

- Continuously monitor quality of particulate beta-gamma airborne activity in selected area.

Physical characteristics

- GM detector(s) - usually pancake type. Some utilize one GM detector to measure activity on filter. Others utilize two GM detectors; one GM detector used to measure activity on filter, and the other GM detector to measures ambient background for background subtraction.
- Filter paper holder assembly in lead shield
- Strip chart recorder
- Mounted on enclosed, portable cart
- Photohelic air flow meter
- Alarm lights for high Activity alarm and low air flow alarm.

Limitations of CAMs

- Low air flow - must be placed near or downwind suspected source
- Poor response to low energy beta
- Lead shield ineffective for high gamma energies, therefore the CAM must be in low background
- Responds to radon, thoron, and daughters which can produce a fluctuating background on recorder.
- Not very portable; approximate weight 500 pounds

Method of sampling

- filtration

Operation and Use

- Initial startup - Check all switches in off position (Master switch and HV switch) plug in power cord (110 V) - Air blower will start and reset any alarms that activate
- Ensure sufficient filter paper
- Turn master switch on and allow two minute warmup
- Turn HV switch on and allow 30 second warmup
- E & I to adjust the following settings: HV level, high and low level alarm settings scale switch overlap setting
- Set recorder speed selector switch; 3/4 in. per minute to ascertain chart moves, 3/4 in. per hour, routine operation
- CAM operating if slow buildup noted on recorder chart.

2.18.06 *Identify the physical and operating characteristics and the limitation(s) of alpha constant air monitors (CAMs).*

ALPHA CONSTANT AIR MONITORS (CAMs)

Continuously monitor quality of particulate alpha airborne activity in selected areas

- Operating characteristics - Air pumping system pulls air through impactor head. Count rate meter monitors planchet which will activate high activity alarm horn and light at preset points.

Physical characteristics

- External cabinet features are: power supply, magnehelic gauge, count rate meter (CRM), recorder chart, power switches, outlets, photohelic air flow meter, and alarm lights (Radiation alarm and Low flow alarm).
- Internal cabinet features are: Annular Kinetic Impactor sample head, blower, planchet (greased with ZnS and Silicone) and the Photomultiplier (PM) tube.

Limitation(s)

- Does not give extremely accurate quantitative alpha measurement, but it gives warning of increase activity and is possible to make estimates.
- Dust buildup and radon-thoron activity affect efficiency.

Method of sampling

- Impaction

Operation and Use

- Initial startup.
- Place new "Alpha Tak" planchet on impactor head: Open light tight box door, move PM tube housing from impactor head, remove any used planchet, place new planchet on impactor head, move PM tube housing back into position, close door, indicate action on recorder chart (date, time, etc.), and take any used planchets to HP office for processing.
- Plug in power cord ensuring all switches are off prior to plugging power cord in.
- Turn on switches in following order: outlet switch, then CRM power switch.
- Set CRM to x 1 scale.
- Set alarm to desired level.
- Set CRM PHA/GROSS switch to GROSS.
- Notify E & I and/or supervisor of any malfunctions.

SUMMARY

This lesson covered air sampling equipment in relation to types used, operational and physical characteristics, limitations, and methods of sampling. The RCT uses this information to identify and assess the hazards presented by airborne contamination and establish protective requirements for work performed in airborne contamination areas.

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Course Title: Radiological Control Technician
Module Title: Counting Room Equipment
Module Number: 2.19

Objectives:

- 2.19.01 Describe the features and specifications for commonly used laboratory counters 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 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
 - f. Source check
 - g. Procedure for sample counting

- 2.19.03 Describe the following features and specifications for commonly used gamma spectroscopy systems.
 - a. Detector type
 - b. Detector shielding
 - c. Detector window
 - d. Types of radiation measured
 - e. Procedures

INTRODUCTION

An overview of counters, scalers and associated equipment will describe the basic functions of counting equipment used to detect radiation activity. 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. Stand-alone counters or scalers measure gross activity while spectroscopy systems perform spectrum analysis to identify and quantify activity from specific nuclides. The common uses of counting room equipment in various facilities will be discussed.

A variety of counting equipment is used. There are both manual and automated counting systems. There is shielded equipment to measure radioactivity just above background levels. There is equipment to measure gross counts of alpha, beta and gamma to determine if surface contamination limits are met. There is 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).

The counting systems use various types of detectors, including gas proportional counters for alpha and beta radiation; sodium iodide, scintillation detectors for gamma spectroscopy; zinc sulfide (ZnS) scintillation detectors for alpha radiation; liquid scintillation for tritium and carbon 14; surface barrier (semiconductor) detectors for alpha spectroscopy, lithium drifted germanium (GeLi semiconductor) detectors for gamma spectroscopy, and high purity, germanium (HPGe semiconductor) detectors for gamma spectroscopy.

The most common uses of the equipment are to count smears, swipes and air filters. Nose swipes are also counted as one way to test if an individual has been exposed to airborne radioactive contamination. 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).

References:

1. "Radiation Detection and Measurement," Glenn F. Knoll, 1979.
2. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5th ed.; Pacific Radiation Corporation; 2008.
3. "Operational Health Physics," Harold J. Moe, 1988.
4. ANSI N323A.
5. Various Manufacturer Technical Manuals.

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.

Detector Type

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. The principle used to accomplish this is pulse height discrimination. 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 mg/cm^2) and use pulse height discrimination to distinguish alphas from betas.

Alpha detectors are generally either gas proportional counters, ZnS scintillators, or silicon semiconductors.

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.

Detector Shielding

To reduce the background, shielding is often used. Betas can be shielded with aluminum or plastic, while typical gamma shielding is a few inches of lead.

Detector Window

Since alphas have a short range the windows are thin, typically 1 mg/cm^2 (or 0.25 mil plastic). 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. 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.

Types of radiation

Some of the detectors discussed in objectives 1 and 2 are designed for alphas, some for betas, and some will count both. Gamma spectroscopy is discussed in Objective 2.19.03. Most nuclides emit more than one type of radiation, but beware of exceptions (like Be-7 or C-14).

Beta background is greater than alpha, so alpha detectors use pulse-height discrimination to differentiate between alphas and betas.

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.

Operator adjustable controls

Counting room systems have a timer to allow the operator to measure the number of counts per minute (cpm). The most common count time is 1 minute, but the count time can be selected by the operator.

Sources

National Institute of Standards and Technology (NIST) standard sources are used to check the systems. Common sources are Pu-239 for alpha and Sr-90 for beta.

Procedures

Procedures generally include:

- background count
- source check
- sample count
- background subtraction
- divide by time to get cpm
- correct for 4 pi efficiency to get dpm
- record the data

2.19.01	<p><i>Describe the features and specifications for commonly used laboratory counters or scalers:</i></p> <ol style="list-style-type: none"> a. <i>Detector type</i> b. <i>Detector shielding</i> c. <i>Detector window</i> d. <i>Types of radiation detected and measured</i> e. <i>Operator-adjustable controls</i> f. <i>Source check</i> g. <i>Procedure for sample counting</i>
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Sample Holder SH-4 with HP210 and ESP

The simplest system for counting smears is the portable contamination survey instrument, the Eberline smart portable ESP with hand probe HP210.

Recall from lesson 2.17 that the HP-210 probe is a pancake GM detector with a thin (1.4 to 2 mg/cm²) window, suitable for detecting contamination from beta emitting nuclides, and alphas above 3 MeV. The HP210T is shielded with tungsten to reduce gamma background. The HP210AL is shielded with aluminum to reduce beta background.

The problem with using the HP210 for quantitative measurements (e.g. to satisfy release criteria) is one of ensuring a precise geometry. The SH-4 sample holder solves this problem by holding the sample in a fixed position directly under the HP210 detector.

Eberline Scintillation Alpha Counter SAC-4

The Eberline SAC-4 is a scintillation alpha counter. The scintillation phosphor is ZnS powder on a plastic light pipe. The system is a self contained unit with the detector and associated electronics housed in a single unshielded box. The detector and sample are both in a light tight can, so no window is required between the ZnS detector and the sample.

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.) The sample holder in the slide drawer is adjustable. It can be moved closer to the detector for thin samples. However, 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.

The electronic package consists of the high voltage power supply used to power the photomultiplier tube and determine its amplification, and a linear amplifier. The linear amplifier output provides a 0 to 10 volt pulse signal to the discriminator that is set to 1.25V above the base line. Only pulses with amplitudes above 1.25V will be counted. This will discriminate against betas because they will produce smaller pulses.

The output from the discriminator is counted by a six decade light emitting diode (LED) readout. 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. This scaler can also be operated in a manual mode which will continue to count until reset by the operator.

A Pu-239 source is used to check the system prior to each operating shift. Background counts are conducted as a part of the performance check and to check for detector contamination. The detector and sample drawer are easily removed for decontamination if required.

The gross count rate is obtained by dividing total counts by the time in minutes. Background counts (typically 0.3 cpm) are subtracted from gross counts to obtain

net counts per minute (cpm). The net count rate (cpm) is corrected for efficiency (as described in lesson 2.03) to convert cpm to disintegrations per minute (dpm).

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.

NMC PC-5 and PC-55 Nuclear Measurement Corporation

The PC-5 and PC-55 systems use gas flow proportional counters as the detectors. The gas used in these detectors is P-10 (90% argon and 10% methane). The systems are self-contained units with the detector and associated electronics housed in the same box. The PC-55 is used to count both alpha and beta. The PC-5 may be manually adjusted to count either alpha or beta. It is normally set to count alpha only. The determination of an alpha count or a beta count is accomplished by pulse height discrimination.

No external shielding is used. Typical background for the unshielded detector is 2 cpm for alphas, and 60 to 100 cpm for betas.

The PC-5 and PC-55 have identical detectors, 2.25 inch in diameter. They may be installed with thin plastic windows with a thickness of 0.25 mil (0.00025 inch, 1 mg/cm²) or they may be installed with no window. If there is no window, the operator must purge with P-10 gas after inserting a sample and closing the gas tight door.

Front panel controls allow for pre-set gas purge times of 12, 36 and 144 seconds. If the detector is installed with a thin plastic window, the normal procedure is to flow the gas continually.

The sample to be counted is placed in a 2 inch diameter planchet and placed in the sample drawer. The sample drawer then slides the sample under the detector. Should the detector drawer or sample holder become contaminated during counting, it is a simple task to remove the detector and drawer for decontamination.

The high voltage supply has a dual operating range of 300 - 1300 volts and 1300 - 2300 volts controlled from a front panel voltage potentiometer. The high voltage determines the optimum setting to discriminate alphas from betas.

The count time is also set by front panel switches providing pre-set counting times in 0.1 minute increments up to 1000 minutes. In the automatic mode, the counter will count to the pre-set time interval. In the manual mode, the counter will continue to count until manually reset.

Two sources are used to check the system for proper operation. The alpha source is Pu-239 electroplated on a nickel disc. The beta source is $^{90}\text{Sr}/^{90}\text{Y}$ (Strontium-90 and its daughter, Yttrium-90). These sources are traceable to NIST (National Institute of Standards and Technology).

- 2.19.02 Describe the 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*
 - f. Source check*
 - g. Procedure for sample counting*

In this section, several automatic counting systems are discussed. The principles are the same as in Objective 2.19.01. The essential differences between the systems in Objectives 2.19.01 and 2.19.02 are:

- complexity of electronics
- number of detectors or automated sample changing
- shielding to reduce background

Canberra 2400

The Canberra 2400 is a low background automatic counting system. 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. A second larger proportional counter, the guard detector, is used to count background. The gas used is P-10 (90% argon and 10% methane). The system may also incorporate a NaI scintillation detector, an option with the Canberra 2400 systems, to simultaneously count gamma rays.

The sample detectors are surrounded by 4 inches of lead shielding to reduce background. Typical background is 0.1 to 1 cpm alpha, 1 to 5 cpm beta, and 100 to 400 cpm gamma.

Canberra 2400 systems are used primarily to count smears or filters. Gross counts for each sample are processed in the computer and converted to dpm. Smear counts above preset limits are highlighted and printed on a separate report.

Performance checks are performed daily or prior to system use. NIST traceable sources of Pu-239 (plutonium), Sr-90 (strontium), and Tc-99 (technetium) are used. The system should be calibrated regularly, or when chi-square values are outside the specified range (see lesson 2.03 for a discussion of the chi-square test).

The system has an automatic sample changer with a dual stack that can handle up to 100 samples. One stack holds the samples to be counted and the other stack stores the samples that have been counted.

Berthold LB770

The Berthold LB770 counting system is a low background semi-automatic counting system. The system uses eleven P-10 gas flow proportional detectors; ten detectors are used to count 10 radioactive samples simultaneously, the other detector is used to count background radiation.

Each detector has a 2.25 inch diameter by 0.25 mil (0.00025 inch) mylar window. The detector bay is shielded with 4 inches of epoxy coated lead. Typical backgrounds are 0.1 cpm alpha and 1 or 2 cpm beta. Typical counting efficiencies are 27% alpha and 42% beta. The planchet is 0.25 inch deep, but a 0.25 inch thick sample would cause major self-shielding problems (see lesson 2.03.01).

The Berthold systems are used primarily to count smears. Both alphas and betas are counted simultaneously in each detector. Determination of alpha or beta activity is accomplished by both pulse amplitude and pulse shape discrimination. 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.

Pu 239 sources are used to check the system for alpha and $^{90}\text{Sr}/^{90}\text{Y}$ sources are used to check for beta. These sources are traceable to NIST (National Institute for Standards and Technology).

The Berthold system is controlled by a computer. Both alpha and beta counts received from each sample are corrected for background and reported in one of three categories, to alert the operator. If the count rate is below the minimum detectable activity (MDA, see lesson 2.03) it falls into category 1. 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. And a count rate that is higher than the upper limit is category 3.

Background and efficiency data are collected for each detector, stored and used for corrections. Pre-set count times are determined by the operator and put into the computer. The count rate data from each detector is corrected and converted to dpm for output to the printer.

Liquid Scintillation Counters, LSC e.g. Packard 2550

Tritium and C-14 emit such low energy betas that even a thin layer of air would stop the betas. To detect this radiation, the sample must be in intimate contact with the detection medium. This is achieved with a liquid scintillation system.

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. This cocktail includes a liquid scintillator to convert the energy deposited by low energy betas into light photons, which are then counted using photomultipliers.

The sample chamber, containing the sample vial and photomultiplier tubes, is light tight. 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". Typical background for beta is 20 cpm.

The LSC system is typically used to count tritium samples from swipes, water samples, and oil samples (vacuum pumps). Tritium is also collected by drawing air samples through silica-gel traps or glycol bubblers.

To calibrate the system, a series of cocktails with known amounts of tritium are prepared. These sources are loaded into the first sample holder (a tray of 10 sample vials). The computer program calculates the detector efficiency for each calibration source.

- 2.19.03 *Describe the following features and specifications for commonly used gamma spectroscopy systems.*
- a. *Detector type*
 - b. *Detector shielding*
 - c. *Detector window*
 - d. *Types of radiation measured*
 - e. *Procedures*

GAMMA SPECTROSCOPY

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. In order to identify specific radionuclides, the unique spectrum of energies particular to each radionuclide is used. This technique is known as spectroscopy.

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 (see lesson 2.18.03). Gamma spectroscopy looks for the characteristic spectrum of gammas from the radioactive decay.

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.

EG&G Ortec Gamma X

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.

Detector Type

The detector is made of n-type high purity germanium semiconductor (HPGe). A 30 liter dewar of liquid nitrogen (LN₂) is used to cool the detector.

Detector Shielding

The detector is shielded by 4 inches of pre World War II steel. This steel is used when a low background is desired as it was manufactured before radioactive fallout (artificial radioactivity, lesson 1.06.03) from nuclear weapons appeared in trace quantities. 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.

Detector Window

The detector window is 0.5 mm thick beryllium.

Types of Radiation Measured

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. The peaks in the spectrum are close together, so excellent resolution is required to distinguish the peaks. 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. Photons from two different nuclides that are 1 keV apart will be seen as two distinct peaks.

Procedures

Energy and efficiency calibrations are obtained using two different sources that are NIST standards. These are mixed sources that contain several gamma emitting nuclides. One source contains isotopes of americium (Am), antimony (Sb), and Europium (Eu). The second mixed source contains isotopes of cadmium (Cd), cerium (Ce), cobalt (Co), strontium (Sr), tin (Sn), cesium (Cs),

and yttrium (Y). The energy and efficiency calibration values are then used by the analysis software.

Specific procedures are written to direct the operator through the sample and computer setup, and the computer analysis. The original copy of the results is kept on file for 1 year and then archived for 75 years.

SUMMARY

This lesson has discussed the detector, shielding, window, types of radiation detected, and procedures for counting room equipment. This knowledge is important to ensure accurate and consistent counting room data for the assignment of proper radiological controls.

SUMMARY

HP210, SH-4 and ESP	Laboratory Counter
Detector type:	GM
Detector shield:	Tungsten for gamma, or aluminum for beta
Detector window:	mica 1.4 to 2 mg/cm ²
Radiation detected:	beta
Controls:	ESP (see lesson 2.17)
Source check:	Sr-90
Eberline SAC-4	Laboratory Counter
Detector type:	ZnS(Ag) scintillator
Detector shield:	None
Detector window:	None
Radiation detected:	alpha
Controls:	Timer: 0.1 to 50 minutes
Source check:	NIST traceable Pu-239 source
NMC PC-5, PC-55	Laboratory Counter
Detector type:	Gas flow proportional counter (P-10 gas)
Detector shield:	None
Detector window:	None, or optional 0.25 mils plastic (1 mg/cm ²)
Radiation detected:	alpha
Controls:	Timer 0.1 minute to 1000 minutes
Source check:	NIST traceable Pu-239 source

Canberra 2400	Low-Background Automatic
Detector type:	Gas flow proportional detector (P-10 gas). Larger guard detector for background. Optional NaI detector for gammas.
Detector shield:	4 inches lead
Detector window:	0.25 mil mylar (1 mg/cm ²)
Radiation detected:	alphas and betas Optional NaI detector for gammas
Source checks:	Pu-239, Sr-90, and Tc-99.
Berthold LB770	Low-Background Automatic
Detector type:	10 gas flow proportional counters (P-10 gas). Plus one detector to count background.
Detector shield:	4 inches of epoxy coated lead
Detector window:	0.25 mil mylar (1 mg/cm ²)
Radiation detected:	alphas and betas
Source check:	NIST traceable Pu-239 calibration source for alpha and ⁹⁰ Sr/Y ⁹⁰ for beta
Liquid Scintillation Counter	
Packard 2550	Low-Background Automatic
Detector type:	Liquid scintillation
Detector shield:	none
Detector window:	none (Light tight housing)
Radiation detected:	Low energy beta from Tritium (or C-14)
Source checks:	LANL calibration sources, with water as quench agent.
EG&G Ortec Gamma-X	Gamma Spectroscopy
Detector type:	HPGe (high purity germanium)
Detector shield:	4 inches pre WW-II steel or 4 inches of coated lead.
Detector window:	Beryllium window 0.5 mm thick
Radiation detected:	gamma and x-ray photons from 3 keV to 4MeV
Source checks:	NIST traceable mixed sources:

GLOSSARY:

cocktail: mixture of liquid scintillation chemicals and sample

discriminator: electronic device that discriminates against small pulses, e.g. to distinguish alphas from betas.

gamma spectroscopy: the use of gamma spectra to identify radionuclides by their characteristic gamma emissions.

multi channel analyzer (MCA): combination of many SCAs, each connected to a scaler channel, to produce a spectrum

resolution: measure of the ability of a system to separate nearby peaks in a spectrum; measure of the widths of the peaks.

single channel analyzer (SCA): combination of a lower level discriminator and an upper level discriminator to select only pulses between the two levels (e.g. to select betas but reject small pulse height noise and large pulse height alphas).