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. Gollnick, Daniel, Basic Radiation Protection Technology, 2nd Edition, Pacific Radiation Corp., Altadena, CA, 1988.
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.
7. Environmental Radioactivity, Iral C. Nelson, Pacific Northwest Labs.

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 shall not cause, in a year, an effective dose equivalent greater than 100 mrem (1 mSv). The 100 mrem effective dose equivalent in a year is the sum of the effective dose equivalent from exposures to radiation sources external to the body during the year plus the committed effective dose equivalent from radionuclides taken into the body during the year. 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.

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."

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 it's 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 Willipa 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 Describe the methods used for environmental monitoring at your facility.

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:

$$Te = \frac{Tr \times Tb}{Tr + Tb}$$

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.

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