Module 2.16 Radiation Survey Instrumentation

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 dose equivalent 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, Daniel A. Gollnick
3. Operational Health Physics, Harold J. Moe
4. ANSI N323A
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 Dose Equivalent**
  
  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/cm², see lesson 1.07.10).

- **Intensity of the Radiation (exposure or dose rate)**
  
  For high radiation fields (>5 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/cm²). 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.
EBERLINE RO-2

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

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:

<table>
<thead>
<tr>
<th>RO-2 Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5 mR/hr</td>
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<tr>
<td>0-50 mR/hr</td>
</tr>
<tr>
<td>0-500 mR/hr</td>
</tr>
<tr>
<td>0-5,000 mR/hr</td>
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</tbody>
</table>

Detector Shielding

The sliding beta shield is made of phenolic as follows:

- RO-2 shield: 400mg/cm² (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 200mg/cm² and the 0.13 cm aluminum case is about 345-mg/cm².

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 are as follows:

- RO-2 windows: 7mg/cm² total; two Mylar windows 3.5mg/cm² (1 mil) each.

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 ±20% for photon energies from 12keV to 7-MeV (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 >70keV 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 °F.

Because the detector is vented to atmosphere, radioactive gases could enter the detector and cause a reading.

**Bicron MicroRem**

The Bicron MicroRem series of instruments are portable, scintillator instruments used to detect and measure gamma and X-ray.

**Detector Type**

The scintillator is an organic cylinder with a tissue equivalent response. In some versions one end is covered by a Mylar window.
The scintillator provides flat energy response. 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.

The detector is not as sensitive as a GM.

**Instrument Operating Ranges**

The instrument range of the MicroRem 0 – 200,000 µRem/hr.

The settings are as follows:

<table>
<thead>
<tr>
<th>MicroRem Ranges</th>
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<tbody>
<tr>
<td>0-20 µRem/hr</td>
</tr>
<tr>
<td>0-200 µRem/hr</td>
</tr>
<tr>
<td>0-2,000 µRem/hr</td>
</tr>
<tr>
<td>0-20,000 µRem/hr</td>
</tr>
<tr>
<td>0-200,000 µRem/hr</td>
</tr>
</tbody>
</table>

**Detector Shielding**

The active volume of the detector is shielded from the sides by the detector wall and the instrument case. Some versions have a mylar window at the front to allow for detection of low energy gammas.

**Detector Window**

The materials and density-thickness value of the two windows, one on the case and one on the detector, for the MicroRem are as follows:

- windows: 7mg/cm$^2$ total; two Mylar windows 3.5mg/cm$^2$ (1 mil) each.

**Types of Radiation Detected/Measured**

The MicroRem is designed to measure gamma and X-ray radiation but will respond to (not measure) beta and neutron radiation. Although a scintillator would respond to alpha radiation, the Mylar windows and the air gap between the two windows eliminates any possibility of an alpha response.
The MicroRem measures photon radiation within ±20% for photon energies above 17-keV. The minimum energy increases to 40keV in the models without a low-energy mylar window.

**Operator-Adjustable Controls**

MicroRem range switch with OFF, HV, and BAT checking positions.

BAT position checks the batteries used to power the instrument circuitry.

**Markings for Detector Effective Center**

The Effective Center markings on the MicroRem are the "crosshairs" on the sides of the instrument case.

**Specific Limitations/Characteristics**

The maximum response time for the MicroRem series of instruments is 15 seconds to reach 90% of the full value, this value decreases on the upper scales to a minimum of 2 seconds.

The MicroRem is not affected by temperature, humidity or air pressure.

### 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**  

**XETEX TELESCAN**

The Xetex Telescan is an extendible, telescoping-rod instrument designed with two Geiger-Mueller (GM) detectors for the measurement of photon exposure.

**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 lowest ranges on the instrument.

The high range detector is the small cylinder in the detector housing, and is used for the upper 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 Telescan 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 Telescan has seven settings. The lower settings utilize the large GM detector and the two settings utilize the smaller GM detector.

<table>
<thead>
<tr>
<th>Telescan Settings</th>
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</thead>
<tbody>
<tr>
<td>0-1 mR/hr</td>
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<tr>
<td>0-10 mR/hr</td>
</tr>
<tr>
<td>0-100 mR/hr</td>
</tr>
<tr>
<td>0-1000 mR/hr</td>
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<tr>
<td>0-10 R/hr</td>
</tr>
<tr>
<td>0-100 R/hr</td>
</tr>
<tr>
<td>0-1000 R/hr</td>
</tr>
</tbody>
</table>

**Detector Shielding**

The two detectors are ‘energy compensated’ to compensate for the GM over-response to low-energy photons. The detectors are partially shielded by probe case.

**Types of Radiation Detected/Measured**

The Telescan will measure gamma and X-ray radiation. The telescan will not respond to alpha radiation due to the shielding of the probe case. 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.

**Operator-Adjustable Controls**

The controls are:
- the range knob with OFF, Battery and the various scales
- a light button to turn on/off the light
- a speaker button to turn on/off the speaker
- a reset button to reset the display to zero

**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 end of the probe indicating the low-range detector.

**Specific Characteristics and Limitations**

Response time for the instrument is varies from 1 to 4 seconds to 90% of full scale, depending on range setting.

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 through the internal speaker.

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 that the Telescan will not saturate, up to 2000 R/hr (twice the highest range).

It is easy to damage the instrument by bending the extendible tube.

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### 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

FAR WEST REM-500

The Far West REM-500 Neutron Detector is a portable instrument for the detection and measurement of the dose equivalent rate from neutron radiation.

Detector Types

The detector is a spherical tissue equivalent proportional counter filled with propane gas. The detector works by measuring the energy deposited by recoil protons cause by neutrons ‘striking’ hydrogen atoms.

Instrument Operating Ranges

The instrument is auto-ranging from 0.001 mRem/hr to 999 Rem/hr. Since the unit has no dead-time correction, the detector will under respond in fields greater than about 100 Rem/hr.

Types of Radiation Detected/Measured

Neutrons are measured. Alpha and beta radiation are not detected because they do not penetrate the detector case. Gamma radiation passes through the detector case but is rejected due to the low energy deposited (basically pulse height discrimination).

Energy Response

The electronics of the REM-500 compensate for energy of the neutrons detected, thus the unit reads in mRem/hr (or Rem/hr). Although it can be set to read in mRad/hr (or Rad/hr).

Operator-Adjustable Controls

The operator controls consist of 5 buttons.

- ON/OFF turns the unit on and off
- MODE switches from rate mode (continuously updated display based on selected time constant) to integrate mode (allows collection of an extended set of data, the unit will gather data until put on hold)
- ALT allows access to the check function and the time constant adjustment
- RESET resets the display to zero
- LIGHT turns on the light.

Specific Characteristics and Limitations
The REM-500 has an attached Cm-244 source to check the electronics and energy calibration of the instrument. Therefore the instrument as a whole must be treated as radioactive material.

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, accurate data is then used to properly assign external exposure controls.