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

Objectives:

2.16.01 List the factors which affect an RCT's selection of a portable radiation survey instrument, and identify appropriate instruments for external radiation surveys.

☞ 2.16.02 Identify the following features and specifications for ion chamber instruments used at your facility:

a. Detector type
b. Instrument operating range
c. Detector shielding
d. Detector window
e. Types of radiation detected/measured
f. Operator-adjustable controls
g. Markings for detector effective center
h. Specific limitations/characteristics.

☞ 2.16.03 Identify the following features and specifications for high range instruments used at your facility:

a. Detector type
b. Instrument operating range
c. Detector shielding
d. Detector window
e. Types of radiation detected/measured
f. Operator-adjustable controls
g. Markings for detector effective center
h. Specific limitations/characteristics.

☞ 2.16.04 Identify the following features and specifications for neutron detection and measurement instruments used at your facility:

a. Detector type
b. Instrument operating range
c. Types of radiation detected/measured
d. Energy response
e. Operator-adjustable controls
f. Specific limitations/characteristics.

References:

1. Radiation Detection and Measurement, Glenn F. Knoll
2. Basic Radiation Protection Technology, Daniel A. Gollnick
3. Operational Health Physics, Harold J. Moe
4. ANSI N323A
5. (Various Manufacturers Technical Manuals)

Instructional Aids:

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

I. MODULE INTRODUCTION

A. Self Introduction

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

B. Motivation

External exposure controls used to minimize the 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 is accurate and appropriate for the source of radiation. This lesson contains information about widely used portable radiation survey instruments.

C. Lesson Overview

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

D. Introduce Objectives

Show O.H.: Objectives

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

II. MODULE OUTLINE

A. General Discussion

1. Measurements using portable radiation survey instruments provide the basis for assignment of practical external exposure controls. In order to establish the proper controls, radiation measurements must be an accurate representation of the actual conditions.

2. Many factors can affect how well the measurement reflects the actual conditions, such as:

   a. Selection of the appropriate instrument based on type and energy of radiation, radiation intensity, and other factors.

   b. Correct operation of the instrument based on the instrument operating characteristics and limitations.

   c. Calibration of the instrument to a known radiation field similar in type, energy and intensity to the radiation field to be measured.

   d. Other radiological and non-radiological factors that affect the instrument response, such as radioactive gases, mixed radiation fields, humidity and temperature.

B. Factors Affecting Instrument Selection

Objective 2.16.01

1. As discussed, the selection of the proper instrument is critical to ensure the data obtained are accurate and appropriate.

2. The instrument is selected based on the characteristics and specifications for that instrument as compared to the required measurements.

3. Several factors should be considered when selecting the instrument.

   a. Type of data required:

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

   b. Measurement of the true 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.

   c. The type of radiation to be measured:

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

   d. The 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).

e. The energy of the radiation to be measured:

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

GM detectors over-respond to low energy gammas; most instruments under-respond to high energy neutrons.

f. Environmental factors:

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

g. Procedural requirements

4. Pre-operational check.

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

a. Physical damage

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

b. Calibration

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

c. Battery

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

d. Zero

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

e. Source check

Perform a source response check as required by procedures.

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

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

a. Detector type.

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

GM detectors over-respond to low energy gammas.

Special detectors are used for neutrons.

b. Operating range.

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

Extendible instruments are generally appropriate for high radiation fields.

c. Detector shielding.

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

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

d. Detector window.

External radiation instruments generally have windows that are about as thick as human skin

(7mg/cm^2). The reason for this is: if the radiation does not penetrate this window then it does not penetrate skin, and so it does not contribute any external dose.

In contrast, contamination monitoring instruments have thinner windows.

e. Types of radiation detected/measured.

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

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

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

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

ZnS scintillation detectors only detect alphas.

NaI scintillation detectors are generally used for gammas.

Neutron detectors are very specialized.

f. Operator adjustable controls.

Portable instruments generally have a battery check.

Ion chambers generally have a zero adjustment.

g. Markings for effective detector center.

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

1) The <u>effective center</u> of the detector, as defined in ANSI N323, is the point within the detector that produces, for a given set of irradiation conditions, an instrument response equivalent to that which would be produced if the entire detector were located at that point.

2) The effective center can be thought of as the point in the detector where the measurement of the radiation intensity is taken.

3) Portable radiation survey instruments are calibrated in a uniform field of radiation larger than the volume of the detector, so that the same radiation intensity is seen throughout the detector.

4) Therefore, the reading "taken" at the effective center represents the rate value in all portions of the detector.

5) If the radiation field over the whole detector is <u>not</u> uniform (such as from surface contamination, radiation streaming, or from a small point source) the exposure rate will not be uniform over the entire detector volume.

6) For non-uniformly irradiated detectors, the displayed value, as "taken" at the effective center, will not reflect the actual exposure rate value and a correction factor may be needed.

C. Eberline RO-2 Series Instruments — Objective 2.16.02

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

   Show actual instruments

   Technical specifications for the RO3 are similar to the RO2.

2. Detector

   a. Operated as an ionization chamber

      Show actual detector with desiccant pack

   b. A phenolic, or plastic, cylinder of 3 in. diameter and 12.7 in^3 (208 cm^3 volume with one end open but covered by a Mylar window)

   c. Fill gas - air (vented to atmosphere through a desiccant pack)

   d. The ion chamber detector is closer to tissue-equivalent than most types, allowing the instrument to accurately access the exposure rate to human tissue.

      1. The detector is approximately tissue equivalent because the materials used for construction have an effective atomic number Z close to that of tissue at 7.5.

      2. Tissue equivalent implies that the detector responds the same as human soft tissue (muscle) would if placed at the same point in the radiation field.

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

   e. Although the detector is not as sensitive as a GM, it is the detector of choice for accessing exposure because of its <u>close correlation to the energy deposited</u> in human tissue by radiation.

3. The RO-2 series instruments are operated in the <u>current mode</u>, or the mode that averages the individual pulse heights per unit time.

a. Individual pulse information is lost; therefore, the electrical signal will not supply information about the type and energy of the individual radiation interactions.

b. However, small pulses, which would be lost in the pulse mode, are averaged along with the other interactions.

4. The instrument range of the Model RO-2 is 0 to 5000 mR/hr.

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

   The settings are as follows:

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

5. The sliding beta shield is made of phenolic as follows:

   Review the concept of density-thickness if necessary

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

6. The materials and density-thickness value of the two windows, one on the case and one on the detector, for the Model RO-2 and RO3 are as follows:

   Show windows on instruments

   - RO-2 windows: 7 mg/cm^2 total, two Mylar windows of 3.5 mg/cm^2 each.

- RO-3 windows: 3.5 mg/cm^2 total, one window of 1 mil Mylar.

7. The Model RO-2 instrument is designed to measure gamma, x-ray, and beta radiation but will detect (not measure) fast neutron radiation.

   a. The instruments will read approximately 10%, in mR/hr, of the true neutron field, in mrem/hr.

   b. Although an ionization chamber would respond to alpha radiation, the Mylar windows and the air gap between the two windows eliminates any possibility of an alpha response.

8. The energy response for the Model RO-2 is as follows:

   a. Measures photon radiation within $\pm$20% for photon energies from 12 keV to 7 MeV (beta shield open). The minimum energy increases to 25 keV if the shield is closed, and to about 40 keV through the side of the instrument.
   Because of the thinner window, the RO3 measures photons from 8 keV.

   b. Measures beta radiation >70 keV with the beta shield open. A beta factor may be appropriate for some situations.

9. Operator-adjustable controls

   a. RO-2 range switch with OFF, ZERO, and BATT checking positions.

   Show controls on the instrument

      1) Switch ranges labeled as 5, 50, 500, and 5,000

      2) ZERO position works in conjunction with ZERO knob to electronically zero the meter.

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

3) BAT1 and BAT2 positions check the two batteries used to power the instrument circuitry.

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

4) OFF position turns the instrument off.

10. The effective center markings on the RO-2 are the "dimples" or depressions on the sides and front of the instrument case.

Show markings on the instrument

11. Specific limitations/characteristics

a. The response time for the RO-2 series of instruments is 5 seconds to reach 90% of the full value.

b. Geotropism, or the effect of gravity on the instrument, causes no greater than a ±2% of full scale change from the actual value.

c. Correction factors may be needed when the radiation field is not uniform over the entire detector.

d. High humidity or moisture can cause leakage currents in the detector and cause erratic meter readings.

1) The detector is vented through a silica gel desiccant, or drying medium, contained in a plastic box.

2) The desiccant can become saturated and will need replacement if the crystals start to turn clear or pink instead of the normal blue color.

e. The detector is vented to atmosphere; therefore, any change in atmospheric density changes the air density in the detector.

1) An increase in temperature will lower the air density in the detector and cause a lower response.

2) An increase in atmospheric pressure will cause an increase in air density in the detector and cause a higher response.

3) Tables are provided in the technical manuals for correcting the instrument response due to changes in pressure or temperature.

4) A change in response of about 10% will occur if the instrument was calibrated at room temperature and used in an environment that is different by about 50 °F.

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

D. Bicron RSO-50 and RSO-500 Instruments

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

   Show instruments.

2. The Bicron RSO series of instruments are very similar in design and construction to the Eberline RO-2 series of instruments.

3. Detector (identical for both models)

   a. Operated as an ionization chamber

   b. A phenolic, or plastic, cylinder of 3 in. diameter and 12.7 in^3 (208 cm^3) volume with one end open but covered by a Mylar window.

   c. Fill gas - air (vented to atmosphere through a silica gel desiccant pack)

4. The Bicron RSO series instruments are operated in the <u>current mode</u>, or the mode that averages the individual pulse heights per unit time.

5. The instrument ranges of the two models are as follows:

a. RSO-500 Ranges:
   0-0.5 R/hr
   0-5 R/hr
   0-50 R/hr
   0-500 R/hr

b. RSO-50 Ranges:
   0-50 mR/hr
   0-500 mR/hr
   0-5 R/hr
   0-50 R/hr

6. The active volume of the detector is shielded from the side by the detector wall and the instrument case and from the bottom by the movable beta shield and two layers of windows.

   a. Detector wall is 200 mg/cm^2 and the 0.13 cm aluminum case is about 345 mg/cm^2.

   b. The materials and density-thickness value of the two windows, one on the case and one on the detector, are the same for both models.

      Show instrument windows.

      1) RSO windows - 7 mg/cm^2 total, both windows are Mylar of 3.5 mg/cm^2 each

   c. The sliding beta shield is made of phenolic and the density-thickness value is the same for both models.

      Show instrument sliding shield.

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

7. The Bicron RSO series of instruments are designed to measure gamma, x-ray and beta radiation but will detect (not measure) fast neutron radiation.

   a. The instruments will read approximately 10%, in mR/hr, of the true neutron field, in mrem/hr.

   b. Like the Eberline RO-2, the Bicron RSO series instruments will not respond to alpha radiation because the alpha particles are shielded before they reach the detector.

8. The energy response of the two models is identical.

   a. Both models measure photon radiation within ±20% for photon energies from 12 keV to 7 MeV (beta shield open).

   b. The minimum energy increases to 25 keV if the shield is closed, and to about 40 keV through the side of the instrument.

   c. Both models measure beta radiation >70 keV.

9. Operator-adjustable controls

   a. RSO-500 range switch with OFF, ZERO, and BATT checking positions.

      1) Switch ranges labeled as 0.5, 5, 50, and 500 R/hr

      2) ZERO position works in conjunction with ZERO knob to electronically zero the meter.

      3) BAT position checks the two batteries used to power the instrument circuitry and detector bias.

      4) OFF position turns the instrument off.

   b. RSO-50 range switch is the same but is labeled 50 and 500 mR/hr and 5 and 50 R/hr.

10. The effective center markings on both Bicron models are the stamped circles with a plus sign in the circle and are located on the sides and front of the instrument case.

    Show markings on instrument.

    If the radiation field over the whole detector is <u>not</u> uniform (e.g. from surface contamination, radiation streaming, or from a small point source) the displayed value may need to be corrected.

11. Specific limitations/characteristics

    a. The <u>response time</u> varies between the two models of Bicron instruments available.

1) RSO-500 - approximately 10 seconds from 0-90% of the final reading.

2) RSO-50 - approximately 5 seconds from 0-90% of the final reading.

b. Correction factors may be needed when the radiation field is not uniform over the entire detector.

c. High humidity or moisture can cause leakage currents in the detector and cause erratic meter readings.

1) The detector is vented through a desiccant, or drying medium, contained in a plastic box.

2) The desiccant can become saturated and will need replacement if the crystals start to turn clear or pink.

d. Like the Eberline RO-2, the detector is vented to atmosphere; therefore, any change in atmospheric density changes the air density in the detector.

1) An increase in temperature will lower the air density in the detector and cause a lower response.

2) An increase in atmospheric pressure will cause an increase in air density in the detector and cause a higher response.

3) Tables are provided in the technical manuals for correcting the instrument response due to changes in pressure or temperature.

4) A change in response of about 10% will occur if the instrument was calibrated at room temperature and used in an environment that is different by about 50°F.

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

E. Victoreen Model 450B

1. The Victoreen 450B is a portable, general purpose, ion chamber survey instrument which uses microprocessor and LCD (liquid crystal display) technology.

   Show instrument.

2. Detector

   a. Operated as an ionization chamber

   b. A Bakelite, or plastic, cylinder of 200 cm^3 volume with one end open but covered by a Mylar window

   c. Fill gas - air (vented to atmosphere through a desiccant pack)

   d. The ion chamber detector is designed as tissue-equivalent, allowing the instrument to accurately access the exposure rate to human tissue.

3. The Victoreen 450B is operated in the <u>current mode</u> as are most ion chambers.

4. Instrument operating range

   a. Overall range is 0-50 R/hr.

   b. The instrument is auto-ranging, or automatically changes scales as required for the instrument reading, and has the following scales:

      1) 0-5 mR/hr

      2) 0-50 mR/hr

      3) 0-500 mR/hr

      4) 0-5 R/hr

      5) 0-50 R/hr

5. The active volume of the detector is shielded from the side by the detector wall and the instrument case and from the bottom by the movable beta shield and windows.

a. Detector wall is 200 mg/cm^2.

b. The sliding beta shield is made of Bakelite, which is a type of plastic and the density-thickness value is 440 mg/cm^2.

c. The two detector windows, one on the detector and one on the case, are made of 1.7 mil Mylar for a total of 3.4 mg/cm^2.

6. The 450B instrument is designed to measure gamma, x-ray, beta and alpha radiation but will detect (not measure) fast neutron radiation.

   a. The instruments will read approximately 10%, in mR/hr, of the true neutron field, in mrem/hr.

7. Energy response

   a. Photon energy response ($\pm$20%) is about 20 keV for slide open, 40 keV for slide closed, and 50 keV from the side.

   b. Beta energies >32 keV can be measured. Tech manual states 100 keV; however, the minimum possible energy is 32 keV.

   c. The alpha response is limited to energies >4 MeV and only if the detector to source distance is less than the alpha range in air. Recall that a 4 MeV alpha travels ~2.5 cm in air.

8. Operator-adjustable controls

   a. Only three external controls are available on the 450B: the ON/OFF switch, the MODE switch, and the meter light button.

   b. The Mode switch is used during calibration and is not enabled for operator use.

   c. The ON/OFF switch turns the instrument on and off.

1) The instrument is auto-ranging and will change the bar graph, digital value, and scale markings as appropriate for the exposure rate value.

2) The instrument has an "auto-zero" feature that eliminates any need for an external zero control.

3) If the batteries are low, then the instrument will display a LOW BAT message.

d. A button switch is provided in the handle for turning the meter face light on and off.

9. The effective center markings on the 450B are the painted-white depressions in the plastic case and are located in the front and on the sides.

Show markings.

10. Specific limitations/characteristics

a. The <u>response times</u> 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:

NOTE: The response times may be greater for a step change from background to a rate value (e.g., background to 4 mR/hr - 9.3 sec).

1) 0-5 mR/hr - 8 sec

2) 0-50 mR/hr - 5 sec

3) 0-500 mR/hr - 2 sec

4) 0-5 R/hr - 2 sec

5) 0-50 R/hr - 2 sec

b. Geotropism, or the effect of gravity on the instrument, causes no greater than a $\pm$1% of full scale change from the actual value.

c. Correction factors may be needed when the radiation field is not uniform over the entire detector, such as for surface contamination beta dose rates.

d. High humidity or moisture could cause leakage currents in the detector and cause erratic meter readings.

1) The detector is vented through a desiccant, or drying medium, contained in a plastic cylinder.

2) The desiccant could become saturated and will need replacement if the crystals start to turn clear or pink.

3) The atmospheric vent on the case has a rubber bladder to allow for changes in temperature and pressure but prevents the free flow of air into and out of the detector casing.

4) The rubber bladder minimizes the effects of high humidity environments and radioactive gases.

e. The detector is vented to atmosphere; therefore, any change in atmospheric density changes the air density in the detector.

1) An increase in temperature will lower the air density in the detector and cause a lower response.

2) An increase in atmospheric pressure will cause an increase in air density in the detector and cause a higher response.

3) The value of the changes due to temperature and pressure are similar to those of other air-vented ion chambers.

F. Eberline Teletector

Objective 2.16.03

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

Show instrument.

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

2. Detectors

    a. Both detectors are sealed GM tubes with halogen-quenched argon fill gas contained in an energy compensating case.

        1) Energy compensation is required in GM detectors to reduce the over-response to low energy photons.

    b. The low range detector is the largest of the two detectors and is located at the end of the detector housing.

        1) The low range detector is used for the three lowest ranges on the instrument.

    c. The high range detector is the small cylinder located on the offset circuit board in the detector housing.

        1) The high range detector is used for the upper two scales.

    d. The GM detectors are very sensitive; however, they lack the direct correlation to energy deposited and are not as useful as ion chamber instruments for assessing exposure or exposure rates.

Detector window
Show window and rubber cap.

3. The Teletector instrument is operated in the <u>pulse mode</u>, or the mode that counts each individual pulse.

    a. Since any ionization in a GM tube causes the same large pulse, any radiation interaction in the detector will be counted.

    b. All the pulses are of the same large size regardless of the energy or type of radiation; therefore, all information on the type and energy of the radiation is lost.

4. The instrument range is 0 - 1000 R/hr.

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

a. 0-2 mR/hr

b. 0-50 mR/hr

c. 0-2 R/hr

d. 0-50 R/hr

e. 0-1000 R/hr

5. Detector shielding

a. The two detectors are shielded by layers of lead and fiber to reduce the low-energy photon response.

b. The low-range detector has a 30 mg/cm^2 mica window and a rubber cap to protect the window.

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

6. The Eberline Teletector will measure x-ray and gamma radiation and can detect (but not measure) beta radiation.

a. Beta response is not accurate and should be used for detection purposes only as stated in the manufacturer's instructions.

b. Alpha response is eliminated by the thicker window and casing.

c. Neutron response is insignificant due to the lower probability of interaction in the small detectors.

7. Energy response

a. The energy response for photon radiation is 80 keV to 3 MeV ($\pm$10%). If the detector is not pulled out of the telescoping rod housing, the minimum photon energy will be higher.

b. Beta particles >160 keV can be detected but not measured.

8. Operator-adjustable controls

a. The only control is the range switch with OFF and B (battery check) positions.

Show instrument.

b. Changing the range at the switch also changes the rotating meter face to the appropriate meter face for that range.

9. Detector effective center markings

a. The effective center of both detectors is indicated by the machined grooves in the detector housing, with the groove closest to the beta window indicating the low-range detector.

b. The high range detector is mounted on a circuit board and is <u>not</u> centered in the detector housing.

1) The offset is indicated by the machined groove in the housing retaining ring at the back end of the detector housing.

2) Any contact readings taken using the high range detector should align the offset indicator so that it points to the source of radiation. Failure to do so will result in inconsistent readings.

10. Specific limitations/characteristics

a. Response time for the instrument is approximately 1 second to 90% of full scale.

b. The sealed detectors do not require correction factors for temperature or pressure.

c. The sealed detectors do not experience problems with humidity or radioactive gases entering the detector.

d. Since beta radiation is only detected and not measured, no correction factors are applied for beta radiation.

e. The 13 ft telescoping rod is durable but can be damaged if twisted or bent.

f. Audible indication is available only through the speaker jack; no internal speaker is installed.

g. The Eberline Teletector is non-saturating on the high ranges up to 30,000 R/hr.

1) For GM detectors, the possibility exists that the detectors become saturated in very high radiation fields. Some GM detector instruments will read zero if the detector becomes saturated.

G. Eberline RO-7 — Objective 2.16.03

1. The RO-7 series instrument provides remote monitoring in high range beta and gamma radiation fields. — Show instrument.

a. The RO-7 consists of a basic digital readout instrument, three interchangeable detectors, and various interconnecting devices.

b. The detectors may be interconnected to the instrument by flexible cables of different lengths, by rigid extensions of different lengths or by use of an underwater housing.

2. Detectors

a. All three detectors are air-vented ion chambers contained in a plastic-lined (phenolic) aluminum housing. The detector fill gas is air. — Show detectors.

b. The detector housing also contains other electronics, such as an operational amplifier and detector identification circuitry.

c. The three available detectors are as follows:

1) The RO-7-LD is a low-range, gamma-only detector with an active volume of about 50 cm^3 and dimensions of 2.5 cm diameter and 10.2 cm long.

2) The RO-7-BM is a mid-range, beta/gamma detector, with beta window, that has an active volume of about 7 cm^3 and dimensions of 2.5 cm diameter and 1.5 cm long.

3) The RO-7-BH is a high-range, beta/gamma detector, with beta window, that has an active volume of about 7 cm^3 and dimensions of 2.5 cm diameter and 1.5 cm long.

d. Each detector is labeled at the connector end of the detector.

NOTE: Two small screws on the label are marked ZERO and CAL. These should only be adjusted at calibration and must not be adjusted by the operator.

3. The RO-7 instrument is operated in the current mode of operation.

4. The operating range of the instrument is dependent on the detector that is connected to the instrument.

a. The range of the RO-7-LD detector is 0-2 R/hr.

b. The range of the RO-7-BM detector is 0-200 R/hr.

c. The range of the RO-7-BH detector is 0-20 kR/hr (20,000 R/hr).

5. Detector shielding

All three detectors have the phenolic liner and aluminum housing.

Detector window
Show window.

a. The RO-7-BM and RO-7-BH detectors each have a 7 mg/cm^2 Mylar window.

b. The Lucite cap for the beta window is 100 mg/cm^2. Show cap.

6. Types of radiation detected/measured

   a. As previously mentioned, the RO-7-LD detector measures only gamma and x-ray radiation.

      1) Both beta and alpha radiation are shielded by the detector housing.

      2) Neutron radiation response is insignificant due to the small size of the detector.

   b. The actual detectors in the RO-7-BM and RO-7-BH detector assemblies are identical.

      1) Both detect and measure gamma, x-ray, and beta radiation.

      2) Alpha response is eliminated by the 7 mg/cm^2 window (same density thickness as the dead layer of skin).

      3) Neutron radiation response is even smaller than the RO-7-LD due to the smaller detector volume.

7. The energy response for the three detectors is as follows:

   a. The RO-7-LD responds to photon radiation between 50 keV and 1.3 MeV (±20%).

   b. The RO-7-BM and RO-7-BH detectors respond to photon radiation differently depending on orientation and whether the Lucite cover is in place.

      1) Lucite cover off - 10 keV to 1.3 MeV (±20%)

      2) Lucite over on - 25 keV to 1.3 MeV (±20%)

      3) Shield on, from the side - 50 keV to 1.3 MeV (±20%)

   c. The beta response for the RO-7-BM and RO-7-BH detectors is for beta energies >70 keV.

8. Operator-adjustable controls

    a. The ON/OFF switch is the only range control because the instrument identifies the detector model and adjusts the readout accordingly.

        1) A low battery condition is indicated by a "colon" under the battery mark on the meter.

    b. The ZERO knob will zero the LCD readout.

    c. A meter face light is turned on/off by the small switch in front of the pistol grip.

9. No markings are provided for the detector effective center.

10. Specific limitations/characteristics

    a. The response time of the basic instrument is 2.5 seconds to 90% of the final reading.

    b. The correction factor for the true beta measurement is 1.5 as recommended by the manufacturer.

    c. Since the detector is air-vented, atmospheric temperature and pressure changes affect the instrument reading.

        1) The instrument response will remain within $\pm$10% for the temperature range of -20 to 160 °F.

        2) A correction table is available in the technical manual for pressure changes.

    d. The detectors are air-vented but do not have a desiccant pack. The detector should be kept dry and out of high humidity environments to prevent leakage currents.

    e. Each detector has associated electronics designed for that particular range. Over-ranging a detector may cause damage to the detector electronics.

f. If the instrument is not calibrated with the underwater housing and the housing is used, the response will be about 5% low. The instrument reading should be multiplied by 1.05 to obtain the corrected response.

g. Interconnecting devices from the detector to the instrument that are available from the manufacturer are the:

1) 15 ft flexible cable

2) 60 ft flexible cable

3) 2 ft rigid extension

4) 5 ft rigid extension

5) Stainless-steel underwater housing with 60 ft of cable

H. Eberline NRD Neutron Sphere

Objective 2.16.04

1. The Eberline NRD sphere is a portable instrument for the detection and measurement of the dose equivalent rate from neutron radiation.

Show instrument.

2. Detector

a. The detector is the Eberline NRD (neutron radiation detector) sphere, which may be connected to the PNR-4 or to an ESP instrument by a coaxial cable.

Show detector.

b. The NRD sphere is a 9 in. diameter, cadmium loaded, polyethylene sphere with a BF_3 proportional tube in the center of the sphere.

c. The BF_3 (boron trifluoride) detector design allows the detection of only thermal neutrons because of the low probability of absorption by boron for other energy neutrons.

Recall thermal neutrons are defined as those neutrons with kinetic energy in thermal equilibrium with their surroundings, or 0.025 eV at STP.

1) The thermal neutron capture reaction with the ^{10}B results in gas ionization pulses caused by the alpha particle product of the reaction.

$^{1}_{0}n + ^{10}_{5}B \rightarrow ^{7}_{3}Li + ^{4}_{2}He$

or

$^{10}_{5}B\ (n,\alpha)\ ^{7}_{3}Li$

2) Detector shielding must be employed if the detector is used for measurement of neutron energies other than thermal.

A less prominent reaction is: $^{10}_{5}B\ (N,2\alpha)\ ^{3}_{1}He$

3. Detector shielding (no window)

a. A polyethylene sphere is used to allow assessment of the dose equivalent from fast and intermediate energy neutrons.

1) The polyethylene has a high percentage of hydrogen which thermalizes the fast and intermediate energy neutrons.

2) Those neutrons that are thermalized in the sphere can be detected in the BF_3 tube.

3) The diameter of the sphere is chosen during design for the neutron energy spectrum expected to be measured.

b. The cadmium loading is a thin, perforated sheet of cadmium surrounding the active volume of the detector and is designed to reduce the over-response of the detector to certain energy neutrons. May over-respond by 100-300% for intermediate neutrons without Cd shield.

4. Operating range

a. The PNR-4 has an overall range of 0-5,000 mrem/hr.

b. PNR-4 has a LIN-LOG meter which means the meter face is a combination of linear and logarithmic scales.

1) The auto-ranging meter uses two meter needles and covers four decades (logarithmic portion).

2) Within each decade of the range, the meter divisions are equally spaced (linear portion).

3) The first needle covers the first two decades of 0-5 mrem/hr and 5-50 mrem/hr.

4) The second needle covers the last two decades of 50-500 mrem/hr and 500-5,000 mrem/hr.

5. Types of radiation detected and measured

   a. The instrument is designed for detection and measurement of fast and intermediate energy neutron radiation.

   b. Alpha and beta radiation are not detected because they do not penetrate the detector shielding.

   c. Gamma radiation passes through the detector shielding but can be rejected by the instrument circuitry up to 500 R/hr (dependent on high voltage setting and desired rejection level). At low rates, photon pulses are rejected. At high rates, pulse pile-up causes a gamma response.

   d. Since the detector is operated in the proportional region, the pulses from the alpha particles are larger than pulses from other interactions and trigger a pulse height discriminator in the instrument circuitry.

   e. The mode of operation for the instrument is the pulse mode so that individual pulses can be discriminated and counted.

6. Energy response for measured radiation

   a. The instrument manufacturer states the instrument response closely follows the theoretical dose equivalent from neutrons over a range of 0.025 eV to about 10 MeV.

   b. The instrument over-responds to intermediate energy neutrons and under-responds to relativistic neutrons.

7. Operator-adjustable controls

    a. The only operator-adjustable control on the PNR4 is the OFF/ON/BAT switch which turns the instrument on and off and allows a check of the battery.

8. Specific limitations/characteristics

    a. The response time depends on which decade of the scale is appropriate.

        1) First decade - 12 seconds

        2) Second decade - 6 seconds

        3) Third decade - 1.5 seconds

        4) Fourth decade - 0.3 seconds

    b. No correction factors are necessary.

    c. The detector is a sealed pressurized cylinder and is not affected by changes in humidity, radioactive gases or changes in atmospheric density.

I. Eberline ASP-1 with NRD Sphere

1. The Eberline ASP-1 with the NRD sphere is a microcomputer-based, analog-display, portable neutron radiation survey instrument.

    Show instrument.

2. The detector (Eberline NRD sphere) is identical to the detector used with the PNR-4 neutron instrument.

3. The mode of operation is the <u>pulse</u> mode.

4. Instrument operating ranges

    NOTE: The operating ranges are established by the calibrating facility based on the detector used and intended purpose by using interchangeable switch labels.

a. The overall range is 0-100 rem/hr and has a useable range of 1 mrem/hr - 60 rem/hr per HP procedure.

1) 0-1 mrem/hr

2) 0-10 mrem/hr

3) 0-100 mrem/hr

4) 0-1,000 mrem/hr

5) 0-10,000 mrem/hr

6) 0-100,000 mrem/hr

5. Detector shielding is the same as previously mentioned for the NRD sphere.

6. The energy response is the same as previously mentioned for the NRD sphere.

7. Operator-adjustable controls

a. The OFF/BAT/HV/range switch has the following functions:

1) The OFF position turns the instrument off.

2) The BAT position checks the instrument battery power supply.

3) The HV position checks the applied high voltage to the detector and should match the value listed on the special label on the instrument case.

4) The range markings are X1, X10, X100, X1K, X10K, and X100K with a meter scale of 0-1.0.

b. The INTEGRATE/FAST/SLOW switch is a three position toggle switch with the following functions:

1) In the INTEGRATE position, the instrument will show the total dose equivalent accumulated since the last time the instrument was reset to zero or turned off.

2) In the FAST position, the response time selected by the microcomputer is for typical survey work.

3) In the SLOW position, the response is slower but with greater accuracy than the FAST position.

c. The LIGHT/RESET switch is a three-position, spring-loaded toggle switch with the following functions:

1) The LIGHT position illuminates the meter face.

2) The RESET position will zero the meter reading for the current
mode (INTEGRATE/FAST/SLOW) setting of the instrument.

3) The RESET switch will cause the "standard current" value to be displayed if held for 5 seconds while in the FAST or SLOW mode.

This is utilized as a calibration check when compared to predetermined value.

d. The SPEAKER is a two-position toggle switch for turning the external speaker on and off.

e. Acoustic (airline-type) head phones can be plugged into the speaker cover on the top of the instrument.

8. As previously mentioned, the NRD sphere has no effective center markings.

9. Specific limitations/characteristics

a. The response time of the instrument is controlled by the microcomputer and is based on the input count rate and whether the mode switch is in FAST or SLOW.

1) In the FAST position, the instrument response time varies between one and ten seconds.

2) In the SLOW position, the instrument response time will vary up to a maximum of 29 seconds.

b. No correction factors are required to correct the displayed value.

c. The sealed detector is not affected by changes in atmospheric density, humidity or radioactive gases.

d. The instrument has a microcomputer controlled "over-range" indication.

1) When the radiation rate exceeds the useful range of the detector, the computer will cause an over-range alarm.

2) When the instrument alarms, the meter needle will sweep back and forth and an interrupted tone will sweep in the speaker.

J. Portable Instrument Specification Chart

1. The specifications for the instruments discussed can be summarized in a chart that shows:

a. manufacturer

b. model

c. detector type

d. operating ranges

e. detector shield

f. detector window

g. radiation measured

h. radiation detected (but not measured)

i. response times.

III. SUMMARY

A. Review major points

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

B. Review learning objectives

IV. EVALUATION

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