Radiation Detection Principles

ACADs (08-006) Covered

1.1.8.1.1	1.1.8.1.2	1.1.8.1.3	1.1.8.1.4	1.1.8.4.5	1.1.8.1.61.1.8.1.7
3.2.2.1.1	3.2.2.2	3.2.2.33.2.3.2	3.2.3.17	3.2.3.18	3.3.3.1
4.4.3	4.5.3	4.5.6	5.4.1.5a	5.4.1.5b	5.4.1.5c
5.4.1.5d	5.4.1.5e				

Keywords

Gas-filled detector, ionization chamber, proportional detector, Geiger-Mueller detector scintillation detector, semiconductor, thermoluminescent detector, characteristics, operating principles, advantages, disadvantages.

Description

This document provides notes to accompany a Powerpoint presentation, references to other resources and student handouts to teach a lesson on radiation detection principles and equipment.

Supporting Material

Rad Measurements Instrument Powerpoint

Headquartered at Indian River State College | 3209 Virginia Avenue Fort Pierce, FL 34981 | 772-462-7172
www.gonuke.org

This material is based upon work supported by the National Science Foundation under Grant No 1104238. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

V. TRAINING OBJECTIVES:

Enabling Objectives:

1. Define the terms listed in Terms and Definitions.
2. Describe the function of each major part of a gas filled detector.
3. Identify factors that can affect the number of ion pairs created in a gas filled detector.
4. Distinguish between the usable and non-usable regions of the gas amplification curve.
5. Demonstrate knowledge of the basic theory of operation and operating characteristics of the following types of gas filled detectors:
    a. Ionization chamber.
    b. Gas proportional.
    c. Geiger-Mueller (GM).
6. List the advantages and disadvantages of the following gas filled detectors:
    a. Ionization chamber.
    b. Gas proportional.
    c. Geiger-Mueller.
7. Demonstrate knowledge of the basic theory of operation and operating characteristics of scintillation detectors.
8. Describe the function of each major part of a scintillation detector.
9. List the advantages and disadvantages of scintillation detectors.
10. Demonstrate knowledge of the basic theory of operation and operating characteristics of semiconductor detectors.
11. List the advantages and disadvantages of semiconductor detectors.
12. Demonstrate knowledge of the basic theory of operation and operating characteristics of thermoluminescent detectors.
13. List the advantages and disadvantages of thermoluminescent detectors.
14. Demonstrate knowledge of the basic theory of operation and operating characteristics of fission chambers.
15. Describe the principle of operation for commonly used neutron detectors.
16. Describe the pre-operational checks required for survey instruments.
17. Identify conditions that might affect survey instrument response.
18. Identify the instruments available for performing radiation surveys.
19. Identify instruments available for performing contamination surveys.
20. Explain instrument efficiency and know factors that can affect instrument efficiency.
21. Calculate instrument efficiency from given information.
22. Explain the operating characteristics and basic electrical circuitry of counting and spectroscopy equipment.
23. Describe the operational checks performed on counting and spectroscopy equipment.
24. Identify unusual conditions that might affect counting and spectroscopy equipment response.
25. Given an instrument model, identify the type of detector it uses.

INTRODUCTION:

There are legal and regulatory restrictions placed upon licensees that make the rapid and accurate detection and measurement of radiation crucial. The detection of radiation is an extremely important part of a health physics technician’s job and involves the determination of the presence of radiation, the measurement of the amount of radiation emanating from the source, and a measurement of the amount of energy deposited in the absorber material by the radiation.

Since radiation cannot be detected by any of the five human senses, it requires the use of radiation detectors. A health physics technician must understand the principles of radiation detection and have knowledge of the various kinds of radiation detectors in order to use the equipment properly. Radiation detection requires an understanding of atomic structure and radiation interactions with matter, as well as, knowledge of radiation types and basic electrical theory.

INPO Warning Flag – High-tech equipment is being purchased and used without a full understanding of its capabilities. Electronic dosimetry systems have been purchased by nearly all plants with the expectation that these devices would replace TLDs, only to later find that they were incapable of accurately and reliably performing that function. (INPO forwarded information regarding electronic dosimeter accuracy and reliability problems to the industry using Nuclear Network.) Other plants have started using new contamination and radiation monitoring equipment without a thorough understanding of the equipment capabilities.

Note: Handout 1 is for additional information.
Handout 2 is a puzzle for students to work during class, as desired.

A. Terms and Definitions **Objective B.1**

1. Anode – the positive charged electrode. In a radiation detector this is often the center wire.
2. Avalanche - The multiplicative process in which a single charged particle accelerated by a strong electric field produces additional charged particles through collisions with neutral gas molecules.
3. Cathode – the negative charged electrode. In a radiation detector this is often the chamber walls.
4. Dead Time - The minimum period of time before a chamber is able to generate another pulse or discharge.
5. Depletion Layer – the sensitive area of a semiconductor detector.
6. Gas Amplification Effect - The increase in total ions due to secondary ionization within a gas filled detector.
7. Geotropism – the effect of gravity on the meter so that a change in movement shows up as a change of the needle reading.

8. Ion - An atomic particle, atom, or chemical radical bearing an electrical charge, either positive or negative. **Objective B.1**
9. Ionization - The process by which a neutral atom or molecule acquires a negative or positive charge. It is the process of removing one or more electrons from a neutral atom. Results in an ion pair, consisting of the negative charged electron and the positive charging remaining atom.
10. Ion pair - Two particles of opposite charge. Normally refers to an ionized atom and an electron stripped from the atom.
11. n-region – the region in a semiconductor that has excess electrons.
12. P-10 Gas - Used in gas flow proportional detectors (90% argon, 10% methane).
13. Phosphor – a material that emits light when it is struck by radiation.
14. p-region – the region in a semiconductor that has excess holes.
15. Quenching Gas - Trace amount of the appropriate gas (ethylnol or halogens) added to a chamber to suppress excessive ionizations. **Objective B.1**
16. Recombination - The recombining of the negative and positive ions to neutralize one another.
17. Resolving Time – the total amount of time from a measurable response in a detector before the detector can measure another pulse.
18. Saturation Current – the voltage at which 100% of the ion pairs produced in a gas filled detector are collected.
19. Scintillation - A flash of light produced in certain phosphors by the absorption of an ionizing particle or photon.
20. Semiconductor – has properties between a conductor and an insulator.
21. Specific Ionization – the number of ion pairs created per unit path length.
22. Thermoluminescence - A property possessed by certain crystals of emitting light upon heating after having been exposed to ionizing radiation.

B. Radiation Detection and Measurement
1. Humans can neither sense nor measure the presence of radiation.
2. Radiation detection is based on the principle that radiation causes ionization and excitation in matter.

3. Detection equipment is designed to measure the amount of ionization and excitation produced by responding to the charged particles which are produced when radiation interacts with matter.
4. The basic difference between various radiation detection devices is the medium in which the interactions occur.

C. Types of Detection Devices
1. Gas Filled Detectors
    a. The primary method of detecting radiation is when radiation ionizes the gas in a filled chamber.
    b. Can result in either pulses representing individual interactions or a current value which is an averaging of many interactions.
    c. Includes ionization chambers, gas proportional detectors, and Geiger- Mueller detectors.

Most widely used method of radiation detection.

2. Scintillation Detectors
    a. Radiation excites the atoms of the detector material, phosphor.
    b. Atoms in phosphor material give off excess energy in the form of light.
    c. Light flashes are counted by the detector.
    d. Scintillation detectors require the use of a photomultiplier tube.

Very effective and very efficient.
The phosphor converts radiation energy to light.

3. Semiconductor Detectors
    a. A semiconductor shares properties with both insulators and conductors.
    b. The conductivity is a function of temperature.
    c. They use a dense material to stop high energy photons.

Used to identify isotopes for gamma spectroscopy.

4. Thermoluminescent Detectors
    a. Certain materials can absorb and store energy from ionizing radiation.
    b. The stored energy is released, in the form of light, when the material is heated.
    c. The amount of light corresponds to the amount of radiation.

Useful for personnel dosimetry.

5. Neutron Detection and Measurement
    a. Fission chambers are basically ion chambers with a fissionable material coating on the inner wall.

    Used for neutron flux monitoring.

    b. Neutron detectors used for dose rate monitoring rely on nuclear reactions which result in charged particles such as protons or alpha particles.

D. Gas Filled Detectors
1. Types of Gas Filled Detectors:
    a. Ionization.
    b. Proportional.
    c. Geiger-Mueller.
2. Simple Gas Filled Detectors

    Objective B.2

    a. Detector consists of an air or gas filled chamber.

    HO-3 Slide 1, Slide 2, and Slide 3

    b. Radiation forms ion pairs in the gas.
    c. The detector has two electrodes.
    anode - positive charged center wire.
    cathode - negative charged chamber wall.

    The anode is well insulated from the chamber wall.

    d. The potential difference between the electrodes produces an electric field inside the chamber.
    e. The electric field between the anode and the cathode draws the ions toward the electrodes.

    Objective B.2

    (1) Positive ions are drawn to the cathode.
    (2) Electrons (negative charge) are drawn to the anode.
    f. A charge collects on the electrode causing a voltage change in the circuit (pulse).
    g. The pulse causes a current to flow in the meter.
    h. The amount of current flow is representative of the energy and amount of radiation that caused the ionization in the detector.
3. Factors That Affect The Number of Ions Pairs Created In A Gas Filled Detector:

    Objective B.3

    a. *Type* of radiation.
    b. *Energy* of the radiation.
    c. *Quantity* of radiation.
    d. *Detector size* and *shape.*
    e. *Pressure* and *type* of fill *gas.*
    f. *Voltage* potential across the electrodes.
4. Gas Amplification Curve
    a. The curve is a graph of the number of ion pairs created as voltage is increased.

    HO-3 Slide 4

    b. The curve has six regions, of which only three can be used for radiation detection.

c. Region of Recombination

(1) Region I on the gas amplification curve.

(2) At zero applied voltage, the ions will not experience any electrical forces and will not move

Objective B.4

Ions will simply recombine.

(3) As the voltage is increased, the ions will move slowly toward the electrodes. The ions may pass close to one another Coulombic force that is stronger than the force moving them toward the electrodes.

The ions will collide and recombine.

(4) When the ions recombine, this removes their electrical charge and they never reach the electrodes to create a signal.

(5) Region I is **<u>not</u>** used for radiation detection.

d. Ionization Region

(1) The ionization region is Region II on the gas amplification curve.

Objective B.4

(2) The voltage is increased to the point that all the ion pairs formed in the gas are collected.

Objective B.5.a

(3) This voltage at which 100 percent of the ion pairs formed are collected is called the *saturation current*.

(4) There is no secondary ionization or gas amplification in the ionization region.

Amplification factor is 1-1.

(5) The advantages of detectors operating in the ionization region are:

Objective B.6.a

(a) Less regulated, less expensive, and more portable power supplies can be used.

(b) The ion chamber response is directly proportional to the dose rate.

Output current is independent of operating voltage. The preferred instrument for setting dose rates.

(c) The number of primary ions is a function of the energy deposited in the detector by the radiation.

(d) Very accurate.

Objective B.6.a

(e) Rugged.

(6) The disadvantages of ionization chamber detectors include:
   (a) Poor sensitivity due to small output pulses.
   (b) High humidity can cause the formation of condensation inside the detector, resulting in leakage paths causing erroneous readings.
   (c) Changes in altitude or temperature changes the density of the fill gas affecting response.
   (d) Expensive.

e. Proportional Region
(1) The proportional region is Region III on the gas amplification curve. **Objective B.4**
(2) In this region, the voltage is increased above the saturation current so that the ions are accelerated rapidly. **Objective B.5.b**
(3) The ions are able to cause further ionization and these secondary ions continue to create ion pairs in a multiplicative process called an *avalanche.* **Objective B.5.b**

Gas amplification.

(4) The gas amplification is proportional to the applied voltage.
(5) The gas amplification is responsible for the formation of a large pulse.
(6) Since the individual pulse can be measured it, is possible to distinguish radiation types.
(7) It takes time for the ions to be collected and for the pulse to be generated. Likewise, it takes time for the pulse to decay. If another ionizing event occurs during this period, the ions from the second event will be collected along with the remaining ions from the first event.

The resulting pulse may not be distinguishable as two pulses by the electronics. The reading will underestimate the actual radiation field.

(8) The period of time between events, so that two distinguishable pulses result, is known as resolving time. **Objective B.5.b**

(a) *Resolving time* is the total amount of time from a measurable detector response before another pulse can be measured.

(b) Resolving time is controlled by the electronics.

(9) In the proportional region, the resolving time is short and does not lead to problems at low count rates, but can result in significant error at high count rates.

(10) The advantages of proportional detectors include: **Objective B.6.b**

(a) Proportional counters can be used to discriminate between different types of radiation.

(b) Proportional counters have a large output pulse, resulting in a good sensitivity, so they can be used to detect low levels of radiation. **Objective B.6.b**

(c) More sensitive than ion chambers.

(11) The disadvantages of proportional detectors include:

(a) The major disadvantage of proportional detectors is that they require a very stable, and often expensive, power supplies. This limits their use as portable instruments, so they are more commonly used for laboratory counting or other stationary locations.

Usually P-10 gas.

(b) The electronics are complex.

(c) Supply of gas is required.

f. Region of Limited Proportionality **Objective B.4**

(1) Region IV on the gas amplification curve.

(2) In this region the voltage is increased above the proportional region and the output is no longer proportional to the input.

(3) The strong field causes increased electron velocity, which results in excited states of higher energies capable of releasing more ion pairs. The positive ions remain near where they were originated and reduce the electric field to a point where further avalanche is impossible.

(4) The small individual avalanches which occur start to interfere with each other.

(5) There is no direct proportionality between the incident radiation and the response.

(6) This region cann**ot** be used for radiation detection.

g. Geiger-Mueller Region **Objective B.4**

(1) The Geiger-Mueller Region is Region V on the gas amplification curve.

(2) The initial energy deposited by the radiation causes an avalanche, just as with the proportional counter; however, when the avalanche reaches the collecting anode, the energy density is so high that light photons are emitted from the electrode. **Objective B.5.c**

(3) These, in turn, interact with the fill gas or the tube walls to produce photoelectrons. The photoelectrons start another avalanche at some other location on the electrode. This process repeats until the anode is completed enveloped by ions.

(4) The voltage has been increased to a point where a single ion pair is enough to cause complete discharge.

(5) In the GM region, any radiation event with sufficient energy to create the first ion pair can cause a large pulse. This explains the high sensitivity of Geiger-Mueller detectors. **Objective B.5.c**

(6) All output pulses are the same size, regardless of their origin.

(7) The magnitude of the pulse produced in the chamber is virtually independent of the energy of incoming radiation.

(8) GM detectors have the same sensitivity to all types of ionizing radiation.

(9) In GM detectors, resolving time can have a significant impact on detector response.

  (a) Resolving time is the minimum time that elapses from the moment of detection of the first ray, or particle until the electronics are able to count a second.

  (b) Resolving time depends upon the electronic circuitry.

  Objective B.5.c

  (c) If two particles enter in rapid succession, the avalanche of ions from the first particle paralyzes the counter and renders it incapable of responding to the second particle.

(10) Another factor that influences GM detectors is dead time. *Dead time* is the time from the initial pulse until another pulse can be produced.

Attachment 1

(11) Dead time occurs because of the effect the large number of positive ions have on the voltage potential across the detector.

During the dead time, the detector can not respond to another ionizing event.

  (a) Negative ions, being electrons, move very rapidly and are soon collected at the anode.

  (b) The massive positive charged ions are slow moving and they form a sheath around the positively charge anode, making it impossible to initiate an avalanche by another ionizing particle.

  Objective B.5.c

  (c) As the positive ion sheath moves toward the cathode, the electric field intensity increases, until a point is reached when another avalanche could be started.

  The time required to attain this electric field intensity is called the dead time.

(12) Dead time can cause saturation in GM survey meters. In a very high radiation field, a conventional GM instrument will show an upswing of the meter needle and then return to zero, even though the instrument is still in a high dose rate field.

Attachment 2

(13) Recovery time is the time from the initial full size pulse to the next full size pulse produced by the detector.

Objective B.5.c
The recovery time includes the dead time.

(a) In the recovery time, the detector can respond, but because of a reduced gas amplification factor, the output pulses are too small to be measured.

(b) The time interval between the dead time and the time of full recovery is called the recovery time.

The sum of the dead time and the recovery time is the resolving time.

(c) Since the avalanche in a proportional counter is limited to a short length of the anode, a second avalanche can be started elsewhere along the anode while the region of the avalanche is completely paralyzed.

(14) Quenching prevents continuous discharge. Quenching gas is used to neutralize the chance of a second pulse when positive ions are collected by the cathode.

Objective B.5.c

Organic alcohol or halogen.

(15) Another property of Geiger-Mueller detectors is energy dependence. This means that the detector does not produce the same pulse output rate when exposed to the same exposure rate produced by gamma rays of different energies.

(a) At low energies, the GM tube is more efficient than air in stopping gamma rays and the tube will read high.

(b) At medium energies, the tube will read correctly.

(c) For high energies, the GM may give an erroneous low reading.

(16) The advantages of Geiger-Mueller detectors are: **Objective B.5.c**

(a) GM detectors are very sensitive and can be used to detect very low levels of radiation.

(b) GM detectors are not readily affected by changes in temperature and pressure.

(c) GM detectors do not require a highly regulated power supply.

(d) GM detectors are relatively inexpensive.

(e) GM detectors are usually rugged.

(17) The disadvantages of the Geiger-Mueller include:

(a) GM detectors are energy dependent.

(b) GM detector response is not related to the energy deposited; therefore, GM detectors cannot directly measure true dose rate.

(c) GM detectors are significantly affected by dead time. **Objective B.6.c**

(d) GM detectors cannot discriminate against different types or radiation.

(e) GM detectors tend to have a low accuracy.

h. Region of Continuous Discharge **Objective B.4**

(1) The Region of Continuous Discharge is Region VI on the gas amplification curve.

(2) The voltage has been increased so high that the insulating properties of the fill gas are broken down and the gas becomes a conductor, resulting in a short circuit between the anode and the cathode. The battery discharges across the detector.

(3) This condition results from the high voltage and the detector does not have to be exposed to radiation for continuous discharge to occur.

(4) Prolonged operation in this region will damage the detector. **Objective B.4**

(5) This region cann**<u>ot</u>** be used for radiation detection.

E. Scintillation Detectors **Objective B.7**

1. The theory of scintillation is based on the luminescent properties of some materials, *phosphors,* to emit light when struck by radiation.
2. The interaction of radiation in a scintillation material results in the material absorbing energy from the radiation.
3. The material will release the energy, in the form of light, when the electron returns to the ground state.
4. The magnitude of the light pulse is proportional to the energy deposited in the scintillation material by the incident radiation.
5. The most commonly used scintillation material is thallium activated sodium iodine crystals.
   a. Sodium iodine is an inorganic crystal and is characterized by high density, high atomic number, and short pulse decay time.
   b. Thallium is added as an impurity to the crystal to create a trap for electrons. **Objective B.7**
   c. Radiation will transfer energy to electrons in the valence band and the electron will move toward the conduction band, creating a hole in the valence band.
   d. The electron will be trapped by the thallium impurity in the forbidden band, which raises it to an excited state.
   e. When the electron returns to the valence band, light is given off.
   f. The intensity of the light flash is proportional to the energy of the radiation responsible for the flash.
6. The light is then increased by the photomultiplier tube. **Objective B.8**
   a. A photomultiplier tube is a vacuum tube with a glass envelope containing a photocathode and a series of electrodes called dynodes.

The photocathode Absorbs the light flashes and emits electrons.

b. Light from the scintillation phosphor liberates electrons from the photocathode. **Objective B.8**
   (1) These electrons are attracted by a voltage drop to the dynode, where several new electrons are liberated.
   (2) These electrons are attracted to the next dynode, where more electrons are liberated.
   (3) This amplification continues through 10 to 14 stages, until the last dynode is reached. A multiplication factor of over 1 million is possible.
   (4) At the anode, a current pulse is formed and sent to the circuits.

7. Other components of a scintillation system are:
   a. Linear amplifier – provides additional amplification for the pulse and shapes the pulse.
   b. Pulse height analyzer – correlates pulse height to radiation energy.
   c. Readout device – accepts pulses whose heights fall within a given range from the upper and lower level discriminators.
8. Scintillation Outputs
   a. Efficiency is nearly 100% for alpha or beta that enters the detector. Efficiency is much less for gamma.
   b. The advantage to using solid scintillation crystals for gamma counting is that the output pulse is directly proportional to the energy of the incident gamma. This makes energy differentiation and nuclide identification possible.
9. In addition to sodium iodide, zinc sulfide and organic scintillators are used.
   a. Sodium Iodide (Thallium Activated), NaI(Th) – used for gamma counting because of its density.
   b. Silver Activated Zinc Sulfide, ZnS(Ag) – has a powdered coating on a transparent material, such as mylar, and is used for alpha counting.
   c. Organic scintillators, both liquid and solid, are used for beta counting.
10. The advantages of scintillation detectors include: **Objective B.9**
   a. high sensitivity.
   b. high efficiency for gamma detection.

c. capacity to handle high counting rates. **Objective B.9**
d. can detect different types and energies.
e. can measure the energy spectrum in gamma emitters.

11. The disadvantages of scintillation detectors include:
    a. detector crystal can be ruined by moisture.
    b. expensive and fragile.
    c. poor low energy gamma response.
    d. can be affected by temperature.
    e. must have a highly regulated power supply.

F. Semiconductor Detectors

1. Semiconductors use a dense ionizing medium, so high energy photons can be stopped completely within the medium. **Objective B.10**
2. A semiconductor acts like a solid state ionization chamber.
    a. In an ionization chamber, the incident radiation produces positive ions and electrons in the gas.
    b. In a semiconductor, the incident radiation produces holes and electrons in a solid material.
3. A semiconductor is a substance that has electrical conducting properties midway between a conductor and an insulator. **Objective B.10**
4. The most commonly used elements for semiconductors are germanium and silicon. Both of these elements have 4 valence electrons and form crystals that are joined by covalent bonds.
5. Absorption of energy by the crystal leads to disruption of these bonds, which results in a free electron and a "hole" in the position formerly occupied by the valence electron.
6. The free electron can move about in the crystal with ease. The hole can also move about in the crystal; an electron adjacent to the hole can jump into the hole, and then leave another hole for the next electron.
7. Connecting the semiconductor in a closed circuit results in a current through the semiconductor as the electrons flow toward the positive terminal and the holes flow through the negative terminal.

8. The operation of a semiconductor depends on an excess of holes or an excess of electrons. By adding certain impurities to the crystal, either an excess number of electrons or an excess number of holes can be created. **Objective B.10**
    a. If an element with 5 valence electrons (arsenic, phosphorous, antimony, bismuth) is added an excess electron exists and is free to move about in the crystal. This is called the *'n region'* of a semiconductor.
    b. If an element with 3 valence electrons (boron, aluminum, gadolinium, indium) is added the crystal has an excess hole and is called the *'p region'* of a semiconductor.
9. If a voltage supply is connected with reverse bias, where the positive terminal is connected to the 'n' region and the negative terminal is connected to the 'p' region, the region around the junction is swept free, by the potential difference, of the holes and electrons in the 'p' and 'n' regions. This region is called the *depletion layer* and is the sensitive area of the detector.
10. When ionizing radiation passes through the depletion layer, electron-hole pairs are produced and are swept apart by the electric field. This results in a pulse in the load resistor. **Objective B.10**
11. Four types of semiconductor detectors are used
    a. Diffused junction silicon - used in the MG electronic dosimeters.
    b. Surface barrier silicon - used in the continuous air monitors.
    c. GeLi (lithium drifted germanium) - used for gamma spectral analysis by chem lab.
    d. HPGe (high purity germanium) - used for the lung and GI detectors on the chair whole body counter.
12. The advantages of semiconductors include: **Objective B.11**
    a. High energy resolution.
    b. High counting rate due to low resolving time.
    c. Very efficient.
13. The disadvantages of semiconductors include: **Objective B.11**
    a. They can be sensitive to light.
    b. They are subject to RF interference.
    c. GeLi detectors must be cooled by liquid nitrogen. **Attachment 3**

G. Thermoluminescent Detectors

1. Some crystals emit light if they are heated after having been exposed to ionizing radiation; they are called thermoluminescent. **Objective B.12**
2. Thermoluminescent crystals are closely related to scintillation materials, except scintillation materials release the light at the time of the incident radiation and thermoluminescent materials absorb and store the energy.
3. Absorption of energy from the radiation excites the atoms in the crystal, which traps the electrons at the impurity sites.
4. Heating the crystal then causes the thermolunescent material to release the energy as light.
5. The total amount of light is proportional to the number of trapped electrons, which is, in turn, proportional to the amount of energy absorbed from the radiation. **Objective B.12**
6. The intensity of the light emitted from the thermoluminescent crystals is thus directly proportional to the radiation dose.
7. For readout the phosphor is heated and the intensity of the luminescense is measured by a photomultiplier tube whose output signal is amplified and sent to a suitable readout instrument.
8. Thermoluminescent crystals are used for personnel monitoring. **Attachment 4**
9. TVA uses a TLD with four crystals.
   a. Element 1:
      (1) Consists of Lithium Tetraborate ($Li_2B_4O_7$:Cu).
      (2) Responds to Beta, Gamma, and Neutrons.
   b. Element 2: **Objective B.12**
      (1) Consists of Lithium Tetraborate ($Li_2B_4O_7$:Cu).
      (2) Responds to high energy Beta, Gamma, and Neutrons.

c. Element 3:
   (1) Consists of Calcium Sulfate ($CaSO_4$:Tm).
   (2) Responds to high energy Beta and Gamma.

d. Element 4:
   (1) Consists of Calcium Sulfate ($CaSO_4$:Tm).
   (2) Responds to Gamma.

10. The plastic holder that holds the elements protects the elements from exposure to light and routine handling damage.
11. The advantages of TLDs include: **Objective B.13**
    a. TLDs can be reused many times.
    b. TLDs are very sensitive and can measure low doses.
    c. TLDs are very accurate.
12. The major disadvantage of TLDs is that, once read, the reading is lost. **Objective B.13**

H. Fission Chambers **Objective B.14**

1. Fission chambers use the principle of fission to detect thermal neutrons.
2. The chamber is usually similar in construction to an ionization chamber, except that the inner wall of the chamber is coated with a fissionable material, usually enriched U^{235}. However, other coating materials, such as U^{238} or Th^{232} can be used.
3. The neutrons interact with the U^{235} and cause fission.
4. Fission chambers can operate in a pulse mode where each neutron interaction is counted separately. This mode is useful only for low levels.
5. Fission chambers operate in the direct current mode when neutron flux levels are high.
6. Fission chambers are used to measure the neutron flux in the core.

I. Neutron Detection

1. Since neutrons do not directly cause ionization, it takes special techniques to detect neutrons. **Objective B.15**
2. TVA uses a Ludlum 12-4 for neutron detection.
3. The Lud 12-4 uses a BF_3 detector in a cadmium loaded polyethylene sphere.

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

4. The polyethylene has a high hydrogen content which thermalizes the fast and intermediate energy neutrons.
5. The cadmium loading is a thin layer surrounding the active volume of the detector and reduces the over response of the detector to certain energy neutrons.

J. Pocket Chamber Dosimeters
1. Pocket chambers are not routinely used at TVA for routine activities due to the use of more state of the art devices such as the electronic dosimeter.
2. Pocket chambers may be required in certain circumstances, such as when RF interference is expected.
3. Pocket chambers work on the principle of electrostatic discharge, similar to a gold-leaf electroscope.
4. The dosimeter consists of a small air-filled chamber in which a split quartz fiber is suspended.

   One side is fixed and the other side is free to move.
5. The movable fiber is displaced electrostatically by charging it.
   a. As both fibers are connected, they have the same charge and repel.
   b. Exposure to ionizing radiation will neutralize some of the charge, allowing the movable fiber to move towards its normal position.

      This movement is read on the scale.
6. Characteristics of Pocket Chambers
   a. Measure only X-rays or gammas.
   b. They are very sensitive to shock and will often go offscale if dropped.
   c. They are affected by humidity and geotropism
   d. They are subject to drift, a gradual loss of charge without the presence of radiation.

K. Using Portable Field Survey Instruments
1. Pre-Operational Checks
   a. Verify the instrument is in calibration.

      Objective B.16
   b. Check the battery by turning the selector switch to the battery position and observing the needle to make sure it falls within the “battery ok” range.

   c. Zero the meter, if applicable.
   d. Do a source check and make sure the instrument response is within the range.
   e. Use the HIS-20 system to log out the instrument.

2. In-Field use and response can be influenced by several factors. **Objective B.17**
   a. *Geotropism* - the influence of gravitational forces on the needle.
   b. Temperature extremes can affect instrument response. Also, very cold temperatures will drain the battery.
   c. Altitude can be an influence on meter response if there is a significant difference between the altitude of calibration and altitude of use.
   d. Shock caused by dropping a meter and damage internal components, even though the instrument appears to be working properly. Any meter that is dropped should not be used until it has been checked for proper operation. **Objective B.17**
   e. Humidity and moisture can cause erroneous readings in some detectors. **Attachment 5**
   f. RF interference from two-way radios, microwaves, etc. can affect detectors.
   g. High radiation fields can cause saturation in some detectors.
   h. Some instruments are energy dependent and can give false readings if high or low energy radiations are present.
   i. Light can influence some detectors. A tiny hole in the window can result in erroneous readings.
   j. Contamination on the surface of the probe or in some cases, Xenon gas, can give false readings.

3. Returning the Instrument
   a. Survey the instrument for contamination.
   b. Use the HIS-20 system to return the instrument.
   c. Report any problems with the instrument supervision.

L. Radiation Survey Instruments

Objective B.18

1. The most commonly used dose rate instrument at TVA and the preferred instrument for setting personnel dose rates is the ionization chamber.

   Explain tissue equivalence.

2. GM instruments, are sometimes preferred for special applications, such as the teletector for radioactive material shipments.
3. The Microanalyst, a scintillation detector, is required for release surveys of bulk materials, such as clean trash.

   State reasons: quick response, sensitive, reach, and audible.

4. Portable area radiation monitors usually have GM detectors.
5. Neutrons must be detected with special neutron detection equipment, such as the Ludlum 12.4.

M. Contamination Survey Instruments

Objective B.19

1. Friskers can be used to count smears for certain applications.
2. Friskers can also be used to direct survey items for low levels of contamination.
3. Other contamination survey instruments may be portable alpha survey instruments such as the Surveyor M.
4. Laboratory counting instruments will be set up for Beta/Gamma and a separate instrument for alpha.

N. Instrument Efficiency

1. Instrument efficiency is a measure of how effective an instrument is at measuring all of the radiation present.

   Objective B.20

2. Instrument efficiency can be affected by several factors:
   a. the type of detector (GM, proportional, scintillation, etc.).
   b. the detector size and shape.
   c. the distance from the detector to the radioactive material.
   d. the type of radiation being measured.

   Objective B.20

   e. the backscatter of radiation toward the detector.
   f. the absorption of the radiation before it reaches the detector.
3. Instrument efficiency is calculated as follows:

   Objective B.21

   net counts/known counts = eff

For Example:

A source of 0.005 microcuries is counted for one minute and the gross counts are 4924. If the background is 39 cpm, what is the instrument efficiency?

First, convert the known source activity from microcuries to dpm.

1 uci = 2.22 E 6 dpm

$$0.005 \text{ uci} \times \frac{2.22 \text{ E } 6 \text{ dpm}}{1 \text{ uci}} = 1.110 \text{ E } 4 \text{ dpm}$$

4924 cpm – 39 cpm = 4885 cpm

$$\frac{4885 \text{ cpm}}{1.110 \text{ E } 4 \text{ dpm}} = 0.440 \text{ or } 44.0\% \text{ efficient}$$

The efficiency factor is calculated simply by taking the reciprocal of the efficiency.

44.0% eff = 2.27 EF

O. Spectroscopy Equipment **Objective B.22**

1. Different isotopes emit gamma rays of varying energies during the decay process.
2. A gamma spectrum can be created by collecting these photons.
3. If enough gamma rays of the same energy deposit their energy in a detector, a spectral peak is created.
4. This peak allows the identification of the radionuclide.
5. The number of counts in the peak, determine the amount of the radionuclide present.
6. The basic circuitry of gamma spectroscopy equipment is:
   a. Detector medium – construction material of the detector. May use a semiconductor material or may use a scintillation material to convert energy from the radiation into light.

      Scintillation equipment only.
   b. Photo-multiplier tube – converts light pulses into low energy electrons.
   c. High voltage power supply – moves the charged particles.
   d. Pre-amp – converts the electrons to a pulse, shapes the pulse, and amplifies the signal.

e. Amplifier- shapes and further amplifies the signal. **Objective B.22**

f. Analog to Digital converter – converts the signal to digital values. The digital values become a memory location, channel, in the multi-channel analyzer.

g. Multi-channel analyzer – analyzes the values in the channels and creates a spectrum that is processed by software to identify the radionuclide that emitted the incident gammas.

7. Spectroscopy Equipment Operational Checks **Objective B.23**

a. Energy calibration – relates the energy of the gamma to a channel number. Performed during initial setup, after replacement of major components, or if unsatisfactory Method Quality Assurance, MQA, performance results are obtained.

Puts known peak in known channel.

MQA is performed once every 6 months.

b. FWHM calibration – Full width half maximum is the width of the peak at half of its maximum height. Performed during initial setup, after replacement of major components, or if unsatisfactory Method Quality Assurance, MQA, performance results are obtained. **Objective B.23**

c. Efficiency calibration – relates the number of counts in the peak to the number of gamma rays being emitted by the source. Performed during initial setup, after replacement of major components, or if unsatisfactory Method Quality Assurance, MQA, performance results are obtained.

d. Resolution check – allows the user to more easily distinguish between peaks of similar energies. The known peak centroid and the expected peak energy must fall within a certain energy range.

Performed monthly.

$$\% \text{ Resolution} = \frac{\text{FWHM (in channel or kev)}}{\text{E (centroid channel)}}$$

e. Source check/response check – shows if the peaks of interest have been reported, shows the % gain of the peaks of interest, and shows the activity of the peaks. The peaks of interest must be reported, the % gain must be within +/- 2%, and the activity of the peaks must be within +/- 3 standard deviations. Performed once per shift. **Objective B.23**

Gain shifts the peaks.

f. Background check – shows if the normal background of the area has changed. Performed once per day.

8. Conditions that might affect spectroscopy equipment response. **Objective B.24**
   a. High humidity.
   b. Abnormal background.
   c. Electronic noise.
   d. Extreme temperature.
   e. Sample geometry.
   f. RF interference.

P. Instrument Models and Detector Types

1. Ionization instrument models used at TVA include: **Objective B.25**
   a. RO-2A.
   b. RO-7. **Slide 5**
   c. RSO-5.
   d. RSO-50. **Slide 6 Attachment 6**
   e. RSO-50E.
   f. RSO-500. **Slide 7**
2. Instrument models used at TVA that incorporate proportional detectors include:
   a. PC-5.
   b. PCM-1B. **Slide 8 Attachment 7**
   c. PCM-2 **Slide 9**
   d. PNR-4 **Slide 10**
3. Geiger-Mueller survey instruments used at TVA include: **Slide 11**
   a. BC-4.
   b. E530-N.
   c. Lud-14C.
   d. Lud 5-5. **Objective B.25**
   e. Lud-177. **Slide 12**
   f. Lud-300.
   g. Lud-375. **Slide 13**

h. RM-14. **Attachment 8**
i. RML-2. **Slide 14**
j. Surveyor-50.
k. Teletector. **Slide 15**

4. Scintillation detectors used at TVA include:
   a. Surveyor M.
   b. MicroAnalyst. **Slide 16**
   c. PM-7. **Slide 17**
   d. SAM-11. **Slide 18**
   e. Fast scan whole body counters. **Slide 19**
5. Semiconductor detectors used at TVA include:
   a. DMC-90.
   b. DMC-100.
   c. DMC-2000.
   d. GeLi detector in chem lab.
   e. Lung and GI detectors in chair whole body counter. **Slide 20 Attachment 9**
   f. MiniEdgar CAMs.

XI. <u>SUMMARY</u>:

This course material covered the gas filled detectors; ionization chambers, proportional detectors, and Geiger-Mueller detectors. It also covered scintillation detectors, semiconductors, and thermoluminescent detectors. The characteristics, operating principles, advantages, and disadvantages for each type of detector were covered.

Hand Out 2

Puzzle - Radiation Detection

IERSKRF

ZEOR

SERPESRU

IINOTNOIZA

CERLEOSNT

COMBIOTRANNIE

HAMTENE

FINCEEFYCI

HODHAOPECOTT

GIHCNQUEN

GEDGUR

NEODYSD

XEIPIESNVEN

REWPO

NOI

DEDA MEIT

DOTCAHE

GARNO

CORDCOENUMIST

SOFISIN BHAMCER

TNRUSEON

MOGSIORPTE

NUSREITOLO

REOCYVER

POORHHSP

CEAVENL

Unscramble each of the clue words.

Take the letters that appear in ◯ boxes and unscramble them for the final message.

Summary of OE 3462 Use of Different Survey Meters Yields Different Results
Limerick Unit 1 Feb. 1, 1986
A HP tech performed a truck release survey for a radioactive material shipment using an Eberline Model E-520 survey meter with an HP-270 external probe. The contact reading on the underside of the trailer was 190 mrem/hr.
The shipment was received at Quadrex and surveyed using a Ludlum Model 14-C survey meter with a Model 44-6 external probe. The contact dose rate was 250 mrem/hr at the same location where the 190 mrem/hr reading was taken prior to shipment.
An investigation determined that the material did not shift during transport. Further investigation yielded the determination that the differences in response of the two instruments was the primary cause. Tests using a Shephard calibration source indicated that when on the X100 scale, the E-520 begins to significantly under-respond at exposure rates greater than 150 – 160 mrem/hr. Although the Ludlum Model 44-6 external probe is identical to that used in the Eberline HP-270 probe, the non-linear X100 scale of the Ludlum 14-C provides the correction of under-respond due to increased dead time.

Summary of U.S. NRC Information Notice No. 86-44 Failure to Follow Procedures When Working in High Radiation Areas
Turkey Point January 8, 1986
An instrument and controls (IC) technician made an unaccompanied, unauthorized entry into a high radiation area to complete repairs on the traversing incore probe, TIP, drive unit with an irradiated TIP withdrawn into the work area. Earlier that same day, with a HP tech providing job coverage, the IC tech had made adjustments to the TIP drive unit (dose rates only 5 to 25 mr/hr), which later enable the IC tech to successfully withdraw the TIP into the accessible TIP drive work area.
During the unauthorized entry, the IC tech received 500 millirem whole body exposure during an approximate 5 minute stay in the work area. Dose rates in the general area were calculated to be 6 R/hr. The radiation level 1 foot away from the work area was 65-70 R/hr on contact with tubing containing the irradiated TIP. The low range GM portable survey instrument used the IC tech upon entering the high radiation area initially moved up the scale to 800 mr/hr and then went rapidly down the scale to zero, when moved closer to the radiation source. The IC tech failed to recognize the malfunctioning survey instrument and stayed in the area to complete his task. The downscale reading was caused by GM detector tube continuous discharge response to intense radiation levels.
In addition to the instrument malfunction, the worker violated several procedures, he failed to notify HP before operating the TIP, he performed work outside of the work order, and he made an entry and worked on the TIP system alone. The worker did not follow radiological posting at the area that read, “High Radiation Area – Keep Out”. He also failed to recognize the malfunctioning survey meter.
NRC imposed a civil penalty of $50,000 on the plant.

Summary of OE 10720 Electronic Dosimetry Alarmed Due to Cell Phone
Commanche Peak September 28, 1999
An electronic dosimeter (Merlin Gerlin or M/G) alarmed on high dose rate due to close proximity to a cell phone. A worker was wearing an electronic dosimeter on his belt adjacent to a cell phone. The dosimeter alarmed on high dose rate. The employee left the work area and checked to see if the alarm stopped. After a few minutes, he returned to work. He asked others in the area if their dosimeters had alarmed or showed a reading other than zero, which they had not. After a while, his dosimeter alarmed again. He again left the area and the alarming stopped. He reentered the area and after a while, the dosimeter alarmed again. After

being prompted by NRC, he then went to the RP office to discuss the issue. They surmised that the alarm was false, caused by his phone, even though the phone was not being used, but in the "on" position.

The worker did not follow requirements from rad worker training that tells workers to wear dosimetry on the chest and specifically not on the belt. Training also states to report to RP if alarms occur.

Summary of OE 15549 Missing TLD Phosphor Insert Events
Ginna January 15, 2003
During a review and comparison of TLD and ED dose measurements, an unusual TLD reading was identified. An inspection of the TLD determined that the TLD phosphor insert was missing. The missing phosphor insert resulted in an incorrect reading of the TLD.
TLDs have been lost, because the hangers (the clear plastic holder with the clip) have come open and the TLD has fallen out. One TLD was damaged by falling out of the hanger and the damage was not discovered until it was processed.

Summary of OE 10328 Portable Radiation Survey Meter Fails Due to Water Intrusion
Perry Unit 1 August 26, 1999
An Eberline Model E520 portable radiation survey meter failed to properly respond to radiation due to water intrusion into the instrument case.
The instrument was used to perform radiation surveys of a shipment of a high integrity container (HIC). There was heavy, driving rain occurring at various times during the preparation and subsequent survey of the shipment. The next day the meter failed the daily source check. Approximately 5 to 8 milliliters of standing water was observed in the can. Additionally, condensation was observed on the instrument electronics component board. After drying for approximately 4 hours, the meter properly responded.
The technical manual for the Eberline E520 has several references to the instrument being "splash-proof" by the use of o-rings throughout. The o-rings seals at the meter face and at the can/meter faceplate were intact. However, no seals or o-rings are installed around the instrument switch or handle connection. These locations employ metal to metal connections, and are points for water intrusion.

Summary of OE 16679 Infrequent Usage of the Eberline RO-7 Dose Rate Survey Meter
Grand Gulf June 18, 2003
A RP tech using an Eberline RO-7 survey meter with a mid-range detector observed what he believed to be an incorrect reading of 'kR/hr" while performing underwater surveys of highly radioactive filters and velocity limiters from control rod blades. The RO-7 liquid crystal display '-' segment for 'kR/hr' is nearly identical to and is located just above the center horizontal '-' segment which is used to indicate a minus or negative meter reading. Knowing the 'kR//hr' indication with the mid-range detector the technician withdrew to check the equipment. The technician using the RO-7 asked the accompanying technician to perform a peer check. The technicians verified they were using a mid-range detector and that all electrical connections were in good condition and properly connected.
With the connectors and power restored the meter indication '-' for 'kR//hr' was as it should be, not energized. The indication for negative '-' meter reading was energized indicating the meter zero requires adjustment for proper indication. The meter zero was appropriately adjusted. This de-energized the negative meter indication.
The technicians resumed the survey. Dose rates were lower than expected. The LCD display now showed three vertically aligned dots with small black text 'BAT' stamped on the meter housing. The lowest '.' Dot was the decimal point symbol and the upper two dots ':' was the colon symbol used to indicate low battery

voltage. The technicians stopped the job and sent the meter to the RP instrument techs. The instrument techs found the batteries were not properly seated.
It is most probable that the meter was misread and that the '-' segment actually observed was the negative '-' segment used to indicate meter zero adjustment is required.

INPO OE 10083 Hot Particles Escape Detection
Surry July 6, 1999
During a refueling outage, HPs tracked seven cobalt-60 hot particles. The hot particles escaped detection at the RCA exit monitors but were detected by the Protected Area exit monitors prior to the workers leaving the station.
Personnel leaving the RCA at Surry are monitored at the RCA exit using Eberline's personnel contamination monitor models PM-6 and PCM. All seven of these workers cleared the RCA exit monitors, but PM-7 monitors at eh Protected Area exit identified hot particles ranging from 3,000 to 300,000 dpm.
The PCM monitor located at the RCA exit and the PM-6 located at the secondary security access are gas flow proportional detectors. They are essentially 100% efficient for beta radiation, where as gamma efficiency for moderate energy photons is approximately 25%. The counting efficiency in gas decreases rapidly with the increase of photon energy due to the decreased photon interaction with the gas. These monitors are relatively insensitive to the higher energy cobalt-60 gamma and may not detect the 0.134 MeV beta's if shielded by clothing or in a location or poor geometry relative to the detector.
The PM-7s located at the protected area exit utilize plastic scintillation detectors. These detectors are only gamma sensitive and are much more efficient in the detection of moderate and high energy photons when compared to gas flow proportional detectors.

Summary of OE 12481 Beta Contamination Outside of Controlled Access
Waterford February 22, 2001
A senior HP tech noted a pump which had been removed from the Waste Gas Analyzer Panel staged near the HP office. The equipment had been cleared through the Merlin Gerin Shielded Tool Monitor (STM) and was staged for pickup by maintenance. Due to personal experience with the Waste Gas Analyzer Panel, the tech took custody of the equipment and brought it back into the CAA control point for further monitoring. After disassembling the pump head, the technician smeared the parts and found removable as well as fixed contamination using a handheld beta-sensitive frisker.
The apparent cause of this event was an overall lack of knowledge that the Waste Gas systems can contain pure beta emitters. This couple with the fact that the scintillation gamma monitor is the industry standard for release of material set up an error trap of over confidence.

Summary of OE13290 Speaker on Electronic Dosimeter Failed to Alert Worker of Dose Alarm
Oconee November 19, 2001
On two separate occasions the speakers on the Merlin Gerin electronic dosimeter (ED) Model DMC-2000 failed to alert workers by not emitting audible dose alarms.
In the first occurrence (11/1/01 at McGuire), the worker was carefully watching dose and noticed that his dosimeter was reading 21 mrem when his dose alarm was set for 20 mrem. He immediately informed RP. Upon investigation, the ED was making a "clicking" noise corresponding to the same cadence at the dose alarm, but no alarm was sounded.
In the second occurrence (11/19/02 at Oconee), the worker entered the RCA with the ED set at a dose alarm setpoint of 15 mrem. Due to an error in the radiation work permit, the worker should have had a dose alarm setpoint of 100 mrem. As the worker was exiting the RCA, he noticed his ED was making a strange noise. It

was determined that the strange noise was due to the ED being in a dose alarm because the dose was 57 mrem and the RWP limit was 15 mrem. The ED dose alarm had malfunctioned.
Duke Power checked all their DMC-2000 speakers with a magnet and found 16 out of 4000 with speaker failures. They were sent to MGPI for evaluation. MGPI found that 7 of these 16 units passed the magnet test. One of them had a visible crack near the speaker and 8 had speaker failures caused during manufacture such as residue/tar, bad circuit or loose speaker adhesive. None of the units showed any signs of abuse by workers. MGPI recommended using the auto-verification capability of the LDM-101 reader to stop DMC-2000s with failed speakers from being assigned to workers. Duke Power evaluated this capability and found that the auto-verification did not work reliably all the time.