



**Course Title:** Radiological Control Technician  
**Module Title:** Counting Room Equipment  
**Module Number:** 2.19

**Objectives:**

- ☞ 2.19.01 Describe the features and specifications for commonly used laboratory counters or scalers:
  - a. Detector type
  - b. Detector shielding
  - c. Detector window
  - d. Types of radiation detected and measured
  - e. Operator-adjustable controls
  - f. Source check
  - g. Procedure for sample counting
  
- ☞ 2.19.02 Describe the features and specifications for low-background automatic counting systems:
  - a. Detector type
  - b. Detector shielding
  - c. Detector window
  - d. Types of radiation detected and measured
  - e. Operator-adjustable controls
  - f. Source check
  - g. Procedure for sample counting
  
- ☞ 2.19.03 Describe the following features and specifications for commonly used gamma spectroscopy systems.
  - a. Detector type
  - b. Detector shielding
  - c. Detector window
  - d. Types of radiation measured
  - e. Procedures

**References:**

1. 10 CFR Part 835 Occupational Radiation Protection
2. DOE-STD-1098-99 U.S. Department of Energy Radiological Control Standard
3. “Radiation Detection and Measurement,” Knoll, G., John Wiley and Sons, New York, 3<sup>rd</sup> Edition, January 2000.
4. “Basic Radiation Protection Technology,” Gollnick, D., Pacific Radiation Corporation, Altadena, 4<sup>th</sup> Edition, January 2000.
5. “Operational Health Physics,” Harold J. Moe, 1988.
6. ANSI N323A
7. Various Manufacturer Technical Manuals
8. TPR-6405 “Health Physics Sample Counter Checks.”
9. TPR-6864 “Liquid Scintillation Counting”

## INTRODUCTION

This chapter describes an overview of the basic functions of counting equipment used to detect radiation activity including counters, scalars, and associated equipment. The RCT uses information from these counting instruments to identify and assess the hazards presented by contamination and airborne radioactivity and establish protective requirements for work performed in radiological areas. Stand-alone counters or scalars measure gross activity while spectroscopy systems perform spectrum analysis to identify and quantify activity from specific nuclides.

The most common uses of the equipment are to count smears, swipes, and air filters. Nose swabs are also counted as one way to test if an individual has been exposed to airborne radioactive contamination. Both workplace and stack emission air filters are counted to measure the concentration of specific radionuclides (e.g. plutonium, and uranium) and classes of radionuclides (e.g. mixed fission products).

A variety of counting equipment is used. There are both manual and automated counting systems. Shielded equipment is used to determine low level radioactivity measuring just above background.

☞ 2.19.01 Describe the features and specifications for commonly used laboratory counters or scalars:

- a. Detector type
- b. Detector shielding
- c. Detector window
- d. Types of radiation detected and measured
- e. Operator-adjustable controls
- f. Source check
- σ Procedure for sample counting

## GENERAL PRINCIPLES

The operational principles of the counting systems used at ICP will be discussed in general and then specific systems will be described.

### Types of Radiation Detected

Counting equipment is used to measure gross counts of alpha, beta, and gamma to determine if surface contamination limits are met. Certain types of equipment measures the energy spectrum for alpha and gamma radiation so that individual isotopes can be identified and quantified (e.g. to determine if an alpha emitter is a plutonium isotope, a uranium isotope, or a radon daughter).

Some of the detectors discussed in objectives 1 and 2 are designed for alphas, some for betas, and some will count both.



Gamma spectroscopy is discussed in Objective 2.19.03. Most nuclides emit more than one type of radiation, but there are exceptions such as Be-7 and C-14.

### **Detector Type**

The counting systems use various types of detectors, including gas proportional counters for alpha and beta radiation; sodium iodide scintillation detectors for gamma spectroscopy; zinc sulfide (ZnS) scintillation detectors for alpha radiation; liquid scintillation for tritium and carbon 14; surface barrier (semiconductor) detectors for alpha spectroscopy, lithium drifted germanium (GeLi) and high purity germanium (HPGe) semiconductor detectors for gamma spectroscopy.

Gamma spectroscopy requires good resolution to distinguish the different energy peaks. GeLi or HPGe semiconductors give the best resolution, though NaI scintillators are also used.

When looking for low levels of radioactivity from alpha emitters (e.g. U, Pu, etc.) it is important to minimize the background count rate from beta and gamma radiation. Beta background is usually greater than alpha, so alpha detectors use pulse-height discrimination to differentiate between alpha and beta. Some gammas will generally be detected in these detectors, but thin detectors have low gamma efficiency, and lead shielding helps to reduce the gamma background still further.

### **Detector Shielding**

To reduce the background, shielding is often used. Betas can be shielded with aluminum or plastic, while typical gamma shielding is a few inches of lead.

### **Detector Window**

Since alpha particles have a low penetrating ability, the windows are thin, typically 1 mg/cm<sup>2</sup> (or 0.25 mil plastic). Some detectors have no window between the sample and the detector; in this case there is a gas purge system for gas proportional counters, or a light tight housing for scintillators. The penetrating ability of alpha particles is so low that self-shielding is often significant, e.g. an alpha emitter buried in a filter may be shielded from the detector by the filter fibers.

### **Operator adjustable controls**

Counting room systems have a timer to allow the operator to measure the number of counts per minute (cpm). The most common count time is 1 minute, but the count time can be selected by the operator.

### **Sources**

National Institute of Standards and Technology (NIST) standard sources are used to calibrate/check the systems. Common sources are Pu-239 for alpha and Sr-90 for beta.

## **LABORATORY COUNTERS OR SCALERS**

In this section, specific laboratory counters or scaler systems are discussed, illustrating the general principles discussed above.

### LUDDLUM MODEL 3030

The Ludlum 3030 scaler is used to measure radioactivity collected on smears and air samples. It can simultaneously assess alpha and beta particle emitting radionuclides.

*Detector type* - The detector consists of ZnS (Ag) crystals adhered to a plastic scintillation material. The sample is placed under the detector via a drawer. The counter is set for a predetermined count time and the sample is counted. The results appear as total counts in the beta and/or alpha channel screens. The results are recorded and divided by the time interval of the count to determine the alpha or beta count rate. These results are divided by the efficiency of the detector to obtain disintegrations per minute. This result is provided as the final activity result.



*Detector Shielding* - The model 3030 has a shielded detector and a chrome plated brass sample tray.

*Detector window* - 0.4 mg/cm<sup>2</sup> aluminized mylar.

*Types of radiation measured* - alpha and beta.

*Operator adjustable controls* - The instrument includes: built in adjustable audio, on/off switch, count button that resets and starts counting, count time in minutes allowing selection of count times of 0.1, 0.5, 1, 2, 5, 10, or a PC position that selects the user-defined count time and volume. The tray switch marked “Tray Latched and Tray Unlatched” must be latched when counting to block all extraneous light from the detector.

*Source Check* - The source check is performed daily before use and described in TPR-6405 “Health Physics Sample Counter Checks.”

*Procedure for counting* - Sample counting may commence when the required background radiation counts and daily source check have been performed.

*Lessons learned* - The instrument is rather heavy, thus use caution when carrying this instrument by the handle because a significant number of them have been returned to the Health Physics Instrument Laboratory (HPIL) with degraded handles. In order to prevent personal injury or equipment damage, users should inspect these instrument handles prior to lifting these instruments.

### LUDDLUM MODEL 2929

The Ludlum Model 2929 is less used and is very similar to the Ludlum Model 3030.

*Detector type* - The Model 2929 is equipped with a scintillation detector also. The scintillation phosphor is ZnS. The two-inch photomultiplier tube is magnetically shielded. The system will accept samples that are one or two inches in diameter. The sample holder in the slide drawer is adjustable; however, if the sample holder position is altered the calibration will no longer be valid.



*Detector Shielding* - The detector window is made of aluminized mylar; however, there is no shielding for the detector.

*Detector window* - 0.4 mg/ square cm aluminized mylar.

*Types of radiation measured* - alpha and beta.

*Operator adjustable controls* - The instrument includes an on/off switch, count switch, hold switch which stops the count cycle without resetting the scaler display, the display provides a range of 0-999,999 counts. A thumbwheel switch is used to preset the count time. This switch used in conjunction with the multiplier switch. The multiplier switch, allows selection of count time multipliers of 0.1, 1.0, 10 or EXT for timing using external clock sources.

*Source Check* - The source check is performed daily before use and described in TPR-6405 “Health Physics Sample Counter Checks.”

*Procedure for counting* - This instrument is not specifically described in TPR-6405. Sample counting is however performed in much the same manner as the Ludlum Model 3030 counting equipment; however the drawer must be closed and locked for the sample counting process to begin.

## **PROTEAN 9400 MPC**

*Detector type* - The detector is an alpha/beta gas flow proportional counter.

*Detector Shielding* - No shielding is used on most units. However it can be fitted with a 1.75 inch lead shield and cosmic radiation guard detectors.

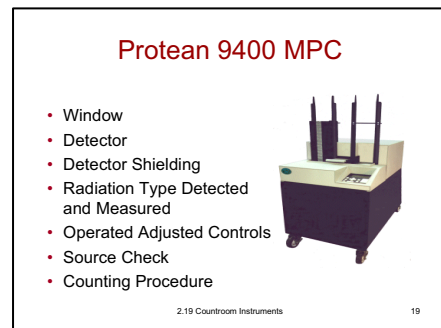
*Detector window* - The window is an ultra thin window of 80 microgram/centimeter squared.

*Types of radiation measured* - Alpha, beta, gamma and x-ray radiation.

*Operator adjustable controls* - The MPC 9400 provides access to six categories of routines through its console. Selections are made through a pushbutton key pad which includes clearly marked function keys and a numerical entry section. In the menu-driven fashion, the operator interacts with each routine sequentially to step through layers of functions and parameters, making entries or changes as necessary.

*Source Check* - The source check is performed daily before use and described in TPR-6405 “Health Physics Sample Counter Checks.” NIST traceable sources are used to calibrate and two check sources are used to determine the reference values. Typically these sources are Cs-137 and Pu-239

*Procedure for counting* - Described in TPR-6405 “Health Physics Sample Counter Checks.”



- ☞ 2.19.02 Describe the features and specifications for low-background automatic counting systems:
- Detector type
  - Detector shielding
  - Detector window
  - Types of radiation detected and measured
  - Operator-adjustable controls
  - Source check
  - Procedure for sample counting

## LOW-BACKGROUND AUTOMATIC SYSTEMS

In this section, several automatic counting systems are discussed. The principles are the same as in Objective 2.19.01. The essential differences between the systems in Objectives 2.19.01 and 2.19.02 are:

- complexity of electronics
- number of detectors or automated sample changing
- shielding to reduce background

You will receive more detailed training on specific instruments depending on your assignment.

### TENNELEC LB-5100 Series and Series 5 XLBS

The Tennelec low background counters are used at some of the ICP RCT counting rooms. The various models are similar in operation; the following is a description of the Tennelec Series 5 XLB.

The Tennelec Series 5 XLB is a low background alpha/beta counter integrated computer controlled system for maximum flexibility.

*Detector type* - The detector is an alpha/beta gas flow proportional counter.

*Detector Shielding* - The molded shield system provides 10 cm (4 in.) of custom molded lead surrounding the detector.

*Detector window* - The window is an ultra thin window of 80 microgram/centimeter squared.

*Types of radiation measured* - Alpha, beta, gamma and x-ray radiation.

*Operator adjustable controls* - Computer controlled system. Fifty planchet sample changer with 100 sample capacity optional. External or sample changer based bar code reader.

*Source Check* - The source check is performed daily before use and described in TPR-6405 “Health Physics Sample Counter Checks.” NIST traceable sources are used to calibrate and two check sources are used to determine the reference values. Typically these sources are Cs-137 and Pu-239.



*Procedure for counting* - Described in TPR-6405 “Health Physics Sample Counter Checks.”

### **Liquid Scintillation Counters, e.g., Beckman LS 6000**



The RCT needs an understanding of the purpose and operation of the liquid scintillation counters. Operating instructions are contained in specific instrument procedures. You will receive additional training depending on your assignment.

Tritium and C-14 emit such low energy betas that even a thin layer of air would stop the betas. To detect this radiation, the sample must be in intimate contact with the detection medium. This is achieved with a liquid scintillation system.

A liquid scintillation counting system uses a "cocktail" that immerses the sample in the counting medium to maximize the detection efficiency for low energy beta emitters. This cocktail includes a liquid scintillator to convert the energy deposited by low energy betas into light photons, which are then counted using photomultipliers.

The sample chamber, containing the sample vial and photomultiplier tubes, is light tight. Since stray electrons can be spontaneously emitted from the photocathode, or by the dynodes in the photomultiplier tube, two tubes are used with coincidence circuitry to reduce this source of noise called "dark current." Typical background for beta is 20 cpm.

The LSC system is typically used to count tritium samples from swipes, water samples, and oil samples (vacuum pumps). Tritium is also collected by drawing air samples through silica-gel traps or glycol bubblers.

To calibrate the system, a series of cocktails with known amounts of tritium are prepared. These sources are loaded into the first sample holder (a tray of 10 sample vials). The computer program calculates the detector efficiency for each calibration source.

- ☞ 2.19.03 *Describe the following features and specifications for commonly used gamma spectroscopy systems.*
- a. *Detector type*
  - b. *Detector shielding*
  - c. *Detector window*
  - d. *Types of radiation measured*
  - e. *Procedures*

## **GAMMA SPECTROSCOPY**

The instruments discussed in objectives 1 and 2 are designed to detect alphas and/or betas, and obtain a gross count of total alpha and beta activity. In order to identify specific radionuclides, the unique spectrum of gamma energies particular to each radionuclide is used. This technique is known as spectroscopy.

Typically, the ICP analytical laboratories operate the gamma spectroscopy instruments, but an RCT needs a basic understanding of the equipment.

Alpha emitters (e.g. Th, U, Pu, Am and their daughters) have characteristic alpha energies, but alpha spectroscopy, detecting the alphas directly, is not optimal, because the energy loss of alpha particles between the sample and the detector smears the energy spectrum (see lesson 2.18.03). Gamma spectroscopy looks for the characteristic spectrum of gamma energies from a radioactive decay.

Gamma spectroscopy usually uses germanium detectors (GeLi or HPGe) because the good resolution obtained with these detectors enables gammas with nearly the same energy to be distinguished or resolved.

### **EG&G Ortec Gamma X**

The Gamma X Spectroscopy system uses an HPGe detector to perform gamma and x-ray spectroscopy in the energy range from 3 keV to 10 MeV.

#### **Detector Type**

The detector is made of high purity germanium semiconductor (HPGe). A 30 liter dewar of liquid nitrogen (LN<sub>2</sub>) is used to cool the detector.

#### **Detector Shielding**

The detector is shielded by 4 inches of pre World War II steel. This steel is used when a low background is desired as it was manufactured before radioactive fallout (artificial radioactivity, lesson 1.06.03) from nuclear weapons appeared in trace quantities. A sample holder inside the shield allows the sample to be positioned at distances from less than 1 cm up to 40 cm from the detector end cap.

#### **Detector Window**

The detector window is 0.5 mm thick beryllium.

#### **Types of Radiation Measured**

The gamma spectrometer is designed to detect gammas and x-rays from gamma emitting nuclides, and sorts the data in a multi channel analyzer to produce a spectrum that is characteristic of the nuclide. The gamma and x-ray energies in the spectrum can be very close together, so excellent resolution is required to distinguish the peaks. Typical resolution from a germanium semiconductor detector (HPGe or GeLi) is better than 1%, which means that if the photon energy is 100 keV, the width of the peak is less than 1 keV. Thus, photons that are 1 keV apart will be seen as two distinct peaks.

**Procedures**

Energy and efficiency calibrations are obtained using two different sources that are traceable to NIST standards. These are mixed sources that contain several gamma emitting nuclides. One source contains isotopes of americium (Am), antimony (Sb), and Europium (Eu). The second mixed source contains isotopes of cadmium (Cd), cerium (Ce), cobalt (Co), strontium (Sr), tin (Sn), cesium (Cs), and yttrium (Y). The energy and efficiency calibration values are then used by the analysis software.

Specific procedures are written to direct the operator through the sample and computer setup, and the computer analysis.

**SUMMARY**

This lesson has discussed the detector, shielding, window, types of radiation detected, and procedures for counting room equipment. This knowledge is important to ensure accurate and consistent counting room data for the assignment of proper radiological controls.

**GLOSSARY:**

*cocktail*: mixture of liquid scintillation chemicals and sample

*discriminator*: electronic device that discriminates against small and large pulses, e.g. to distinguish alphas from betas.

*gamma spectroscopy*: the use of gamma spectra to identify radionuclides by their characteristic gamma emissions.

*multi channel analyzer (MCA)*: combination of many SCAs, each connected to a scaler channel, to produce a spectrum

*resolution*: measure of the ability of a system to separate nearby peaks in a spectrum; measure of the widths of the peaks.

*single channel analyzer (SCA)*: combination of a lower level discriminator and an upper level discriminator to select only pulses between the two levels (e.g. to select betas but rejects smaller noise pulses and large pulses caused by alphas).