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

INTRODUCTION

An overview of counters, scalers and associated equipment will describe the basic functions of counting equipment used to detect radiation activity. 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 scalers measure gross activity while spectroscopy systems perform spectrum analysis to identify and quantify activity from specific nuclides. The common uses of counting room equipment in various facilities will be discussed.

A variety of counting equipment is used. There are both manual and automated counting systems. There is shielded equipment to measure radioactivity just above background levels. There is equipment to measure gross counts of alpha, beta and gamma to determine if surface contamination limits are met. There is equipment to measure 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).

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 semiconductor) detectors for gamma spectroscopy, and high purity, germanium (HPGe semiconductor) detectors for gamma spectroscopy.

The most common uses of the equipment are to count smears, swipes and air filters. Nose swipes 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).

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 Manufacturer Technical Manuals

GENERAL PRINCIPLES

A variety of counting room systems are used. The principles of these systems will be discussed in general and then specific systems will be described.

Detector Type

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 betas and gammas. The principle used to accomplish this is pulse height discrimination. Betas have a range that is about 100 times greater than alphas, so alphas will deposit about 100 times as much energy in a thin detector, producing a larger pulse than betas. Therefore alpha detectors are thin (typically 1 mg/cm^2) and use pulse height discrimination to distinguish alphas from betas.

Alpha detectors are generally either gas proportional counters, ZnS scintillators, or silicon semiconductors.

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.

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 alphas have a short range the windows are thin, typically 1 mg/cm^2 (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 alpha range is so short that self-shielding is often significant, e.g. an alpha emitter buried in a filter may be shielded from the detector by the fibers.

Types of radiation

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 beware of exceptions (like Be-7 or C-14).

Beta background is greater than alpha, so alpha detectors use pulse-height discrimination to differentiate between alphas and betas.

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.

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 check the systems. Common sources are Pu-239 for alpha and Sr-90 for beta.

Procedures

Procedures generally include:

- background count
- source check
- sample count
- background subtraction
- divide by time to get cpm
- correct for 4 pi efficiency to get dpm
- record the data

2.19.01 Describe the features and specifications for commonly used laboratory counters or scalers:
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LABORATORY COUNTERS OR SCALERS

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

Sample Holder SH-4 with HP210 and ESP

The simplest system for counting smears is the portable contamination survey instrument, the Eberline smart portable ESP with hand probe HP210.

Recall from lesson 2.17 that the HP-210 probe is a pancake GM detector with a thin (1.4 to 2 mg/cm^2) window, suitable for detecting contamination from beta emitting nuclides, and alphas above 3 MeV. The HP210T is shielded with tungsten to reduce gamma background. The HP210AL is shielded with aluminum to reduce beta background.

The problem with using the HP210 for quantitative measurements (e.g. to satisfy release criteria) is one of ensuring a precise geometry. The SH-4 sample holder solves this problem by holding the sample in a fixed position directly under the HP210 detector.

Eberline Scintillation Alpha Counter SAC-4

The Eberline SAC-4 is a scintillation alpha counter. The scintillation phosphor is ZnS powder on a plastic light pipe. The system is a self contained unit with the detector and associated electronics housed in a single unshielded box. The detector and sample are both in a light tight can, so no window is required between the ZnS detector and the sample.

The system will accept samples up to 2 inches in diameter by 3/8 inches thick. (Self shielding would be a major problem with samples this thick.) The sample holder in the slide drawer is adjustable. It can be moved closer to the detector for thin samples. However, the SAC-4 is calibrated with the sample holder in a certain position, so if the sample holder is moved, the calibration is no longer valid.

The electronic package consists of the high voltage power supply used to power the photomultiplier tube and determine its amplification, and a linear amplifier. The linear amplifier output provides a 0 to 10 volt pulse signal to the discriminator that is set to 1.25V above the base line. Only pulses with amplitudes above 1.25V will be counted. This will discriminate against betas because they will produce smaller pulses.

The output from the discriminator is counted by a six decade light emitting diode (LED) readout. The timing circuit is synchronized to the line frequency (60 Hz) and provides preset counting times from 0.1 to 50 minutes controlled by front panel switches. This scaler can also be operated in a manual mode which will continue to count until reset by the operator.

A Pu-239 source is used to check the system prior to each operating shift. Background counts are conducted as a part of the performance check and to check for detector contamination. The detector and sample drawer are easily removed for decontamination if required.

The gross count rate is obtained by dividing total counts by the time in minutes. Background counts (typically 0.3 cpm) are subtracted from gross counts to obtain net counts per minute (cpm). The net count rate (cpm) is corrected for efficiency (as described in lesson 2.03) to convert cpm to disintegrations per minute (dpm).

This counting system is used to obtain total activity and the procedures are followed as described in the SAC-4 manual. Each background, source count, and sample count is documented and kept on file.

NMC PC-5 and PC-55 Nuclear Measurement Corporation

The PC-5 and PC-55 systems use gas flow proportional counters as the detectors. The gas used in these detectors is P-10 (90% argon and 10% methane). The systems are self-contained units with the detector and associated electronics housed in the same box. The PC-55 is used to count both alpha and beta. The PC-5 may be manually adjusted to count either alpha or beta. It is normally set to count alpha only. The determination of an alpha count or a beta count is accomplished by pulse height discrimination.

No external shielding is used. Typical background for the unshielded detector is 2 cpm for alphas, and 60 to 100 cpm for betas.

The PC-5 and PC-55 have identical detectors, 2.25 inch in diameter. They may be installed with thin plastic windows with a thickness of 0.25 mil (0.00025 inch, 1 mg/cm^2) or they may be installed with no window. If there is no window, the operator must purge with P-10 gas after inserting a sample and closing the gas tight door.

Front panel controls allow for pre-set gas purge times of 12, 36 and 144 seconds. If the detector is installed with a thin plastic window, the normal procedure is to flow the gas continually.

The sample to be counted is placed in a 2 inch diameter planchet and placed in the sample drawer. The sample drawer then slides the sample under the detector. Should the detector drawer or sample holder become contaminated during counting, it is a simple task to remove the detector and drawer for decontamination.

The high voltage supply has a dual operating range of 300 - 1300 volts and 1300 - 2300 volts controlled from a front panel voltage potentiometer. The high voltage determines the optimum setting to discriminate alphas from betas.

The count time is also set by front panel switches providing pre-set counting times in 0.1 minute increments up to 1000 minutes. In the automatic mode, the counter will count to the pre-set time interval. In the manual mode, the counter will continue to count until manually reset.

Two sources are used to check the system for proper operation. The alpha source is Pu-239 electroplated on a nickel disc. The beta source is $^{90}Sr/Y^{90}$ (strontium 90 and its daughter, Yttrium 90). These sources are traceable to NIST (National Institute of Standards and Technology).

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

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

Canberra 2400

The Canberra 2400 is a low background automatic counting system. The primary detector is a gas flow proportional counter with a 2.25 inch diameter thin window, used to count both alpha and beta activity. A second larger proportional counter, the guard detector, is used to count background. The gas used is P-10 (90% argon and 10% methane). The system may also incorporate a NaI scintillation detector, an option with the Canberra 2400 systems, to simultaneously count gamma rays.

The sample detectors are surrounded by 4 inches of lead shielding to reduce background. Typical background is 0.1 to 1 cpm alpha, 1 to 5 cpm beta, and 100 to 400 cpm gamma.

Canberra 2400 systems are used primarily to count smears or filters. Gross counts for each sample are processed in the computer and converted to dpm. Smear counts above preset limits are highlighted and printed on a separate report.

Performance checks are performed daily or prior to system use. NIST traceable sources of Pu-239 (plutonium), Sr-90 (strontium), and Tc-99 (technetium) are used. The system should be calibrated regularly, or when chi-square values are outside the specified range (see lesson 2.03 for a discussion of the chi-square test).

The system has an automatic sample changer with a dual stack that can handle up to 100 samples. One stack holds the samples to be counted and the other stack stores the samples that have been counted.

Berthold LB770

The Berthold LB770 counting system is a low background semi-automatic counting system. The system uses eleven P-10 gas flow proportional detectors; ten detectors are used to count 10 radioactive samples simultaneously, the other detector is used to count background radiation.

Each detector has a 2.25 inch diameter by 0.25 mil (0.00025 inch) mylar window. The detector bay is shielded with 4 inches of epoxy coated lead. Typical backgrounds are 0.1 cpm alpha and 1 or 2 cpm beta. Typical counting efficiencies are 27% alpha and 42% beta. The planchet is 0.25 inch deep, but a 0.25 inch thick sample would cause major self-shielding problems (see lesson 2.03.01).

The Berthold systems are used primarily to count smears. Both alphas and betas are counted simultaneously in each detector. Determination of alpha or beta activity is accomplished by both pulse amplitude and pulse shape discrimination. The scalers in the Berthold systems are similar to those used in the PC-55 but with more sophisticated electronics that provide improved pulse shaping from the linear amplifier and better discrimination of both pulse amplitude and pulse shape.

Pu 239 sources are used to check the system for alpha and $^{90}Sr/^{90}Y$ sources are used to check for beta. These sources are traceable to NIST (National Institute for Standards and Technology).

The Berthold system is controlled by a computer. Both alpha and beta counts received from each sample are corrected for background and reported in one of three categories, to alert the operator. If the count rate is below the minimum detectable activity (MDA, see lesson 2.03) it falls into category 1. A count rate that falls within predetermined limits, usually above MDA but below the limit for release to a controlled area (RadCon table 2.2) is category 2. And a count rate that is higher than the upper limit is category 3.

Background and efficiency data are collected for each detector, stored and used for corrections. Pre-set count times are determined by the operator and put into the computer. The count rate data from each detector is corrected and converted to dpm for output to the printer.

Liquid Scintillation Counters, LSC e.g. Packard 2550

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 make a gross count of total alpha and beta activity. In order to identify specific radionuclides, the unique spectrum of energies particular to each radionuclide is used. This technique is known as spectroscopy.

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 gammas from the 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 coaxial photon 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 n-type high purity germanium semiconductor (HPGe). A 30 liter dewar of liquid nitrogen (LN_2) 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 alpha emitting nuclides, and sort the data in a multi channel analyzer to produce a spectrum that is characteristic of the nuclide. The peaks in the spectrum are 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. Photons from two different nuclides 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 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. The original copy of the results is kept on file for 1 year and then archived for 75 years.

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.

SUMMARY

HP210, SH-4 and ESP	**Laboratory Counter**
Detector type:	GM
Detector shield:	Tungsten for gamma, or aluminum for beta
Detector window:	mica 1.4 to 2 mg/cm^2
Radiation detected:	beta
Controls:	ESP (see lesson 2.17)
Source check:	Sr-90

Eberline SAC–4	**Laboratory Counter**
Detector type:	ZnS(Ag) scintillator
Detector shield:	None
Detector window:	None
Radiation detected:	alpha
Controls:	Timer: 0.1 to 50 minutes
Source check:	NIST traceable Pu-239 source

NMC PC–5, PC-55 Laboratory Counter

Detector type:	Gas flow proportional counter (P-10 gas)
Detector shield:	None
Detector window:	None, or optional 0.25 mils plastic (1 mg/cm^2)
Radiation detected:	alpha
Controls:	Timer 0.1 minute to 1000 minutes
Source check:	NIST traceable Pu-239 source

Canberra 2400 **Low-Background Automatic**

Detector type:	Gas flow proportional detector (P-10 gas). Larger guard detector for background. Optional NaI detector for gammas.
Detector shield:	4 inches lead
Detector window:	0.25 mil mylar (1 mg/cm^2)
Radiation detected:	alphas and betas Optional NaI detector for gammas
Source checks:	Pu-239, Sr-90, and Tc-99.

Berthold LB770 **Low-Background Automatic**

Detector type:	10 gas flow proportional counters (P-10 gas). Plus one detector to count background.
Detector shield:	4 inches of epoxy coated lead
Detector window:	0.25 mil mylar (1 mg/cm^2)
Radiation detected:	alphas and betas
Source check:	NIST traceable Pu-239 calibration source for alpha and ^{90}Sr/Y^{90} for beta

Liquid Scintillation Counter
Packard 2550 **Low-Background Automatic**

Detector type:	Liquid scintillation
Detector shield:	none
Detector window:	none (Light tight housing)
Radiation detected:	Low energy beta from Tritium (or C-14)
Source checks:	LANL calibration sources, with water as quench agent.

EG&G Ortec Gamma-X **Gamma Spectroscopy**

Detector type:	HPGe (high purity germanium)
Detector shield:	4 inches pre WW-II steel or 4 inches of coated lead.
Detector window:	Beryllium window 0.5 mm thick
Radiation detected:	gamma and x-ray photons from 3 keV to 4MeV
Source checks:	NIST traceable mixed sources:

GLOSSARY:

cocktail: mixture of liquid scintillation chemicals and sample

discriminator: electronic device that discriminates against small 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 reject small pulse height noise and large pulse height alphas).

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