LA-UR-17-26091
Approved for public release; distribution is unlimited.

Title: RCT: Module 2.03, Counting Errors and Statistics, Course 8768

Author(s): Hillmer, Kurt T.

Intended for: Training

Issued: 2017-07-20

Disclaimer:
Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

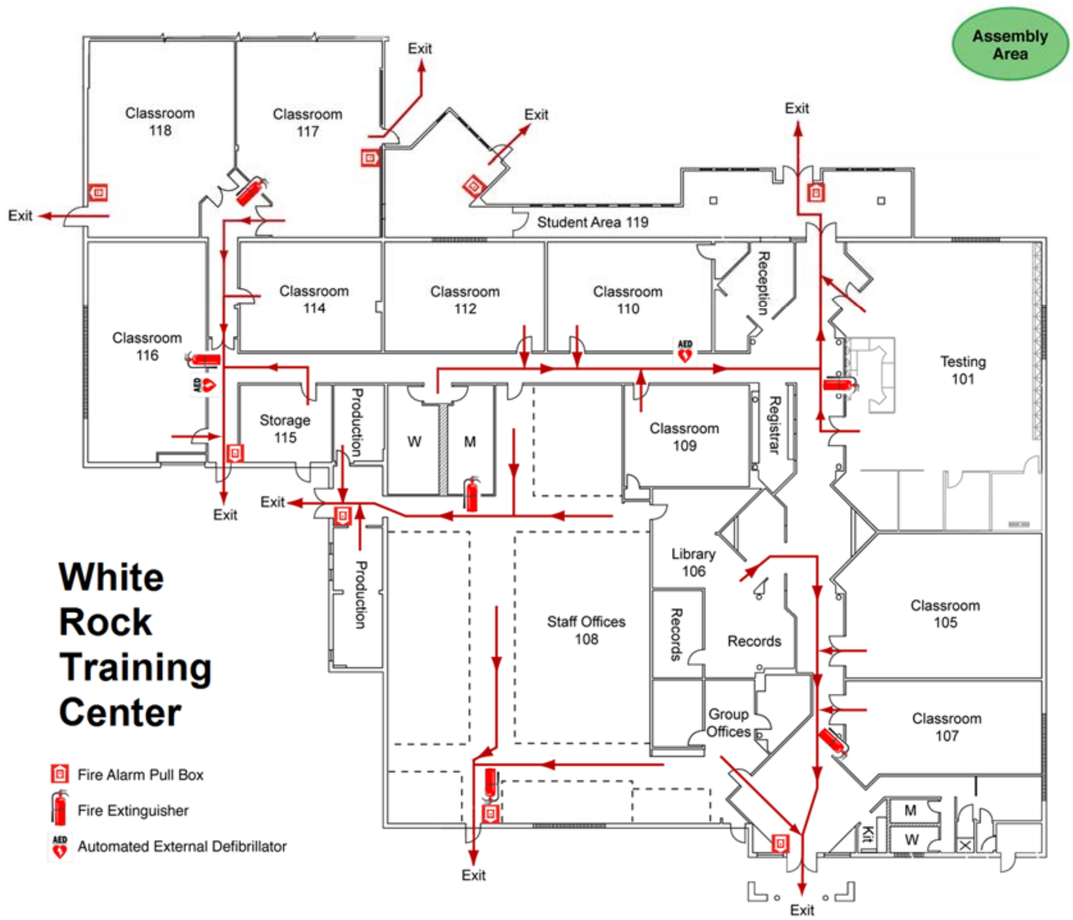
RCT: Module 2.03, Counting Errors and Statistics

Course 8768

April 2017

Los Alamos
NATIONAL LABORATORY
EST. 1943
Operated by Los Alamos National Security, LLC for the NNSA

This training course was prepared by Los Alamos National Security, LLC (LANS) under Contract DE-AC52-06NA25396 with the U.S. Department of Energy, National Nuclear Security Administration (DOE/NNSA). All rights in the material are reserved by DOE and LANS pursuant to the contract. This training course is presented with the understanding that the information and materials provided were developed based on specific circumstances present at the Los Alamos National Laboratory at the time of publication. Those circumstances may or may not be similar to conditions present at other locations represented by participants in this course. The course materials and information will need to be adapted accordingly. NEITHER THE DOE/NNSA, NOR LANS, NOR ANY OF THEIR EMPLOYEES, MAKES ANY WARRANTY, EXPRESS OR IMPLIED, OR ASSUMES ANY LEGAL LIABILITY OR RESPONSIBILITY FOR THE ACCURACY, COMPLETENESS, OR USEFULNESS OF ANY INFORMATION, APPARATUS, PRODUCT, OR PROCESS DISCLOSED AND WILL NOT BE LIABLE FOR DIRECT OR INDIRECT DAMAGES RESULTING FROM USE OF THIS MATERIAL.



Institutional Training Services Group Leader *Cindy Dutro*
Course Manager *Kurt Hillmer, RP-PROG*
Technical Advisor *Kurt Hillmer, RP-PROG*
Editor/Compositor *Lisa Rothrock*

Course Number: 8768
April 2017
LA-UR-17-XXXX
Controlled Document Number: RCT_2.03_CountErr&Stats_8768_SM,R2.0

Contents

Introduction **1**
Course Overview 1
Course Objectives 1
Target Audience 3
Acronyms 3

General Types (Sources) of Errors **5**
Self-Absorption 5
Backscatter 6
Resolving Time 6
Geometry 7
Random Disintegration 8

Applications of Counting Statistics in Sample Analysis **13**

Mode, Median, Mean **15**

Given a Series of Data, Determine the Mode, Median, or Mean **17**
Determine the Mode 17
Determine the Median 17
Determine the Mean 17

Variance and Standard Deviation **19**
Variance 19
Standard Deviation 19
Gaussian Deviation 20

Calculating Standard Deviation **21**

Purpose of a Chi-Squared Test **23**

Criteria for Acceptable Chi-Squared Values **25**

Quality Control (QC) Charts **27**

Maintenance and Review of QC Charts **29**

Calculating Warning and Control Limits **31**

System Operating Limits 31

Determining Efficiencies and Correction Factors 33
Counter Efficiency 33

Calculate Efficiencies and Correction Factors 35
Calculate Efficiency 35
Calculating Activity 35
Calculating Correction Factors 35

Meaning of Counting Data Reported as x ± y................................ 37
Error Calculations 37

Results to Desired Confidence Level 39

Purpose of Determining Background 41
Reducing Background 42

Method and Requirements for Determining Background 45

Purpose of Performing Sample Planchet Maintenance 47

Planchet Maintenance for Counting Systems................................ 49
Propagation of Error 49

Methods to Improve Statistical Validity of Sample Measurements51

Detection Limits.. 53

Calculate Detection Limit Values for Counting Systems 59

Determining Crosstalk 61
Discrimination 61
Origin of Crosstalk 62
Calibration Sources and Crosstalk 62

Acceptable Values of Crosstalk for Counting Systems 65

Voltage Plateaus... 67

Method of Performing a Voltage Plateau on Counting Systems.. 69

Introduction

Course Overview

Radiological sample analysis involves the observation of a random process that may or may not occur and an estimation of the amount of radioactive material present based on that observation. Across the country, radiological control personnel are using the activity measurements to make decisions that may affect the health and safety of workers at those facilities and their surrounding environments.

This course will present an overview of measurement processes, a statistical evaluation of both measurements and equipment performance, and some actions to take to minimize the sources of error in count room operations.

This course will prepare the student with the skills necessary for radiological control technician (RCT) qualification by passing quizzes, tests, and the RCT Comprehensive Phase 1, Unit 2 Examination (TEST 27566) and by providing in-the-field skills.

Course Objectives

2.03.01 Identify five general types of errors that can occur when analyzing radioactive samples, and describe the effect of each source of error on sample measurements.

2.03.02 State two applications of counting statistics in sample analysis.

2.03.03 Define the following terms:
a. mode
b. median
c. mean

2.03.04 Given a series of data, determine the mode, median, or mean.

2.03.05 Define the following terms:
a. variance
b. standard deviation

2.03.06 Given the formula and a set of data, calculate the standard deviation.

2.03.07 State the purpose of a Chi-squared test.

2.03.08 State the criteria for acceptable Chi-squared values at LANL.

2.03.09 State the purpose of creating quality control (QC) charts.

2.03.10 State the requirements for maintenance and review of QC charts at LANL.

2.03.11 State the purpose of calculating warning and control limits.

2.03.12 State the purpose of determining efficiencies and correction factors.

2.03.13 Given counting data and source assay information, calculate efficiencies and correction factors.

2.03.14 State the meaning of counting data reported as x ± y.

2.03.15 Given counting results and appropriate formulas, report results to desired confidence level.

2.03.16 State the purpose of determining background.

2.03.17 State the method and requirements for determining background for LANL counting systems.

2.03.18 State the purpose of performing sample planchet maintenance.

2.03.19 State the method and requirements for performing planchet maintenance for LANL counting systems.

2.03.20 Explain methods to improve the statistical validity of sample measurements.

2.03.21 Define “detection limit,” and explain the purpose of using detection limits in the analysis of radioactive samples.

2.03.22 Given the formula and necessary information, calculate detection limit values for LANL counting systems.

2.03.23 State the purpose and method of determining crosstalk.

2.03.24 State the criteria for acceptable values of crosstalk for LANL counting systems.

2.03.25 State the purpose of performing a voltage plateau.

2.03.26 State the method of performing a voltage plateau on LANL counting systems.

Target Audience

This course is designed for LANL new-hire RCT employees with no operational experience.

Acronyms

BF	backscatter factor
ccpm	corrected counts per minute
cpm	counts per minute
CF	correction factor
CL	confidence level
GM	Geiger-Muller
LANL	Los Alamos National Laboratory
LC	critical detection level
LD	minimum significant activity level
LET	linear energy transfer
LLD	lower limit of detection
MDA	minimum detectable activity
QC	quality control
RCT	radiological control technician

Notes. . . .

General Types (Sources) of Errors

> 2.03.01 Identify five general types of errors that can occur when analyzing radioactive samples, and describe the effect of each source of error on sample measurements.

Five general sources of error associated with counting a sample, assuming that the counting system is calibrated correctly, are

1. self-absorption,
2. backscatter,
3. resolving time,
4. geometry, and
5. the random disintegration of radioactive atoms (statistical variations).

Self-Absorption

When a sample has an abnormally large amount of material on the sample media (or the sample itself is large), it could introduce a counting error due to self-absorption, which is the absorption of the emitted radiation by the sample material itself. Self-absorption could occur for

- liquid samples with a high solid content or
- air samples from a high dust area.

The use of improper filter paper may introduce a type of self-absorption, especially in alpha counting (i.e., absorption by the media, or filter).

When counting samples, ensure that the correct sample medium is used and that the sample does not become too heavily loaded with sample material. Count room personnel should routinely check samples for improper media or heavily loaded samples.

Backscatter

Counting errors due to backscatter occur when the emitted radiation traveling away from the detector is reflected, or scattered back, to the detector by the material in back of the sample. The amount of radiation that is scattered back will depend on the type and energy of the radiation and the type of backing material (reflector). The amount of backscattered radiation increases as the energy of the radiation increases and as the atomic number of the backing material increases. Generally, backscatter error is a consideration only for particulate radiation, such as alpha and beta particles. Because beta particles are more penetrating than alpha particles, backscatter error will be more pronounced for beta radiation.

The ratio of measured activity of a beta source counted with a reflector compared with the count of the same source without a reflector is called the backscatter factor (BF).

$$BF = \frac{counts\ with\ reflector}{counts\ without\ reflector}$$

.

Normally, backscatter error is accounted for in the efficiency or conversion factor of the instrument. However, if different reflector materials, such as aluminum and stainless steel, are used in calibration and operation, an additional unaccounted error is introduced (this additional error will be about 6% for stainless steel vs aluminum). Count room personnel must be aware of the reflector material used during calibration of the counting equipment. Any deviation from that reflector material will introduce an unaccounted error and reduce confidence in the analysis results.

Resolving Time

Resolving time (or dead time) is the time interval that must elapse after a detector pulse is counted before another pulse can be counted. Any radiation entering the detector during the resolving time will not be recorded as a pulse; therefore, the information on that radiation interaction is lost. As the activity, or decay rate, of the sample increases, the amount of information lost during the resolving time of the detector is increased. As the losses from resolving time increase, an additional error in the measurement is introduced. Typical resolving time losses are shown in Table 1.

Note: The total time required for the Geiger-Muller (GM) tube to give the maximum pulse height is the recovery time.

Table 1. Typical Resolving Time Losses

Count rate (cpm)	GM Tube [1]	Proportional [2]	Scintillation [3]
20,000	1.7%	< 1%	< 1%
40,000	3.3%	< 1%	< 1%
60,000	5.0%	< 1%	< 1%
100,000	8.3%	< 1%	1.0%
300,000	25.0%	< 1%	3.5%
500,000	42.0%	1.5%	5.8%

[1] GM tube: 50μs resolving time
[2] Proportional detector: 2μs resolving time
[3] Scintillation detector: 7μs resolving time

Resolving time losses can be corrected using Equation (1):

$$R = \frac{R_0}{1 - R_0 \tau} \quad , \qquad (1)$$

where

R = the "true" count rate (in cpm),

R_0 = the observed count rate (in cpm), and

τ = the resolving time of the detector (in minutes—"tau")

Count room personnel should be aware of the limitations for sample count rate, based on procedures and the type of detector in use, to prevent the introduction of additional resolving time losses. This issue is especially true for counting equipment that uses GM detectors.

Geometry

Geometry-related counting errors result from the positioning of the sample in relation to the detector. Normally, only a fraction of the radiation emitted by a sample is emitted in the direction of the detector because the detector does not surround the sample. If the distance between the sample and the detector is varied, then the fraction of emitted radiation that hits the detector will change. This fraction will also change if the orientation of the sample under the detector (i.e., side-to-side) is varied.

An error in the measurement can be introduced if the geometry of the sample and detector is varied from the geometry used during instrument calibration. This variation is especially critical for alpha counting, where any change in the sample-to-detector distance also increases (or decreases) the chance of attenuation of the alpha particles by the air between the sample and detector.

Common geometry-related errors include the following:

- Placing or piling smears and/or filters on top of each other in the same sample holder (which moves the top sample closer to the detector and varies the calibration geometry).
- Using deeper or shallower sample holders than those used during calibration (changes the sample-to-detector distance).
- Adjusting movable bases in the counting equipment sliding drawer (which changes the sample-to-detector distance).
- Using too many or inappropriate sample holders or planchets (which changes the sample-to-detector distance).
- Not fixing sources in position (which can change the geometry and reduce reproducibility).
- Improperly setting Plexiglass shelving in the counting chamber.

Random Disintegration

The fifth source of general counting error is the random disintegration of the radioactive atoms.

Statistics

Statistics is a branch of mathematics that deals with the organization, analysis, collection, and interpretation of statistical data. No definition of statistical data is available. However, Webster's does define a statistic as “an estimate of a variable, as an average or a mean, made on the basis of a sample taken from a larger set of data.” This last definition is applicable to our discussion of counting statistics.

When we take samples, we use the data derived from analysis of those samples to make determinations about conditions in an area, in water, in air, etc., assuming that the sample is representative. Therefore, we have estimated conditions (a variable) on the basis of a sample (our smear, water sample, or air sample) taken from a larger set of data.

Over the years, various methods and observations have identified three models that can be applied to observations of events that have two possible outcomes (binary processes). Fortunately, we can define most observations in terms of two possible outcomes. For example, look at Table 2.

Table 2. Probabilities of Success

Trial	Definition of Success	Probability of Success
Tossing a coin	"heads"	1/2
Rolling a die	"a six"	1/6
Observing a given radioactive nucleus for a time, t	The nucleus decays during the observation	$1-e^{-\lambda t}$

For each of the processes that we want to study, we have defined a trial (our test), defined a success and a failure (two possible outcomes), and determined the probability of observing our defined success.

To study these processes, we can use proven, statistical models to evaluate our observations for error. Consider the possibilities when throwing two dice.

As indicated in Table 3, 36 outcomes are possible when throwing 2 dice.

Table 3. Possibilities of Rolling Dice

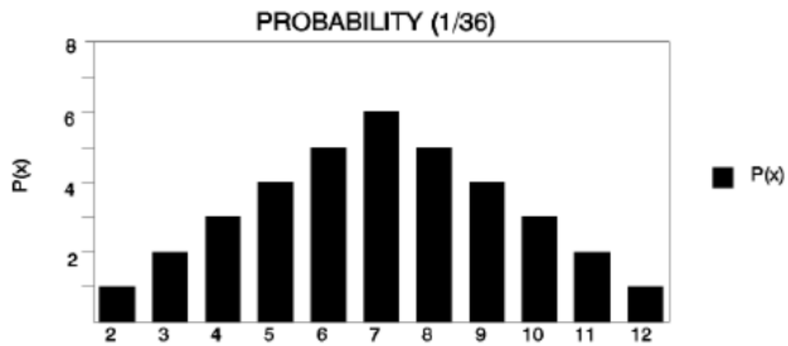
Result	Possibilities	No. of Possibilities
2	1&1	1
3	1&2, 2&1	2
4	1&3, 2&2, 3&1	3
5	1&4 ,2&3, 4&1, 3&2	4
6	1&5, 2&4 ,3&3, 4&2, 5&1	5
7	1&6, 2&5, 3&4, 4&3, 5&2, 6&1	6
8	2&6, 3&5, 4&4, 5&3, 6&2	5
9	3&6, 4&5, 5&4 ,6&3	4
10	4&6, 5&5, 6&4	3
11	5&6 ,6&5	2
12	6&6	1

In our study of this process, if we define a success as throwing a number between 2 and 12, the outcome is academic. All trials will be successful, and we can describe the probabilities that throwing any individual number between the range of 2 and 12 inclusive would add up to 1.

If we define a success as throwing a particular number, we can define the probability of our success in terms of the number of possible outcomes that would give us that number in comparison with the total number of possible outcomes.

If we were to take two dice, roll the dice a large number of times, and graph the results in the same manner, we would expect these results to produce a curve such as the one shown in Figure 1.

Figure 1. Probability in Binary Process



The area under the curve can be mathematically determined and would correspond to the probability of success of a particular outcome. For example, to determine the probability of throwing a particular number between 2 and 12, we would calculate the area under the curve between 2 and 12. The result of that calculation is 36.

This is what statistics is all about: random binomial processes that should produce results in certain patterns that have been proven over the years. The three models that are used are distribution functions of binomial processes with different governing parameters. These functions and their restrictions are Binomial Distribution and Poisson Distribution.

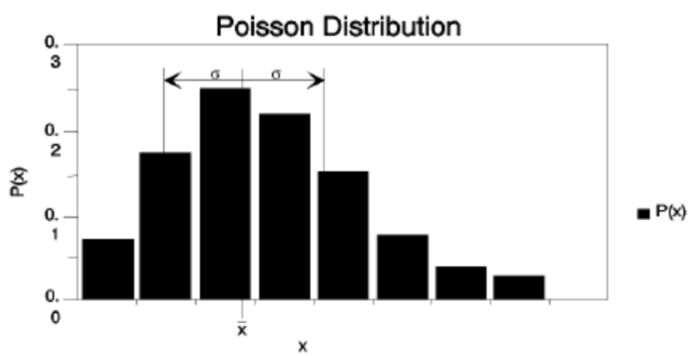
Binomial Distribution

This distribution is the most general of the statistical models and is widely applicable to all processes with a constant probability; however, it is not widely used in nuclear applications because the mathematics are too complex.

Poisson Distribution

A simplified version of binomial distribution is the Poisson (pronounced "pwusówn") distribution, which is **valid when the probability of success, P(x), is small**. If we graphed a Poisson distribution function, we would expect to see the predicted number of successes at the lower end of the curve, with successes over the entire range if sufficient trials were attempted. Thus, the curve would appear as seen in Figure 2.

Figure 2. Predicted Successes for Poisson



The Poisson model is used mainly for applications involving counting system background and detection limits, where the population (i.e., number of counts) is small. We will discuss this model in greater detail later.

Gaussian Distribution

Also called the “normal distribution,” the Gaussian (pronounced “Gowziun”) distribution is a further simplification that is **applicable if the average number of successes is relatively large but the probability of success is still low**. A graph of a Gaussian distribution function is shown in Figure 3.

Figure 3. Predicted Successes for Gaussian Distribution

Note that the highest number of successes is at the center of the curve, the curve is bell shaped, and the relative change in success from one point to the adjacent one is small. Also note that the mean, or average number of successes, is at the highest point, or at the center of the curve.

The Gaussian, or normal, distribution is applied to counting applications where the mean count or success is expected to be greater than 20; it is used for counting system calibrations and operational checks, as well as for normal samples containing activity. It may or may not include environmental samples (i.e., samples with very low activity).

Applications of Counting Statistics in Sample Analysis

2.03.02 State two applications of counting statistics in sample analysis.

Two purposes for statistical analysis of count room operations are to

- predict the inherent statistical uncertainty associated with a single measurement, thus allowing us to estimate the precision associated with that measurement; and
- serve as a check on the normal function of nuclear counting equipment.

Notes. . . .

Mode, Median, Mean

2.02.03 Define the following terms:

a. mode
b. median
c. mean

Mode – An individual data point that is repeated the most in a particular data set.

Median – The center value in a data set arranged in ascending order.

Mean – The average value of all the values in a data set.

Notes. . . .

Given a Series of Data, Determine the Mode, Median, or Mean

2.03.04 Given a series of data, determine the mode, median, or mean.

Determine the Mode

In the set of test scores shown in Figure 4, a score of 95 occurs (i.e., is repeated) more often than any other score. This score is the mode.

Determine the Median

In the same set of test scores, the median is the score in the middle—where one-half of the scores are below and the other half are above the median. The median for the test scores in Figure 4 is 90.

Determine the Mean

The mean is found by adding all of the values in the set together and dividing by the number of values in the set. The mean of the nine test scores is 89.

Figure 4. Sample Data Set

Student	Test Score
Susan	80
Richard	82
Greg	86
Peter	88
Andrew	90
Wanda	92
Randy	95
Jennifer	95
Sarah	95

Equation of the Mean

The mean is often expressed using special symbols, as in Equation (2):

$$\bar{x}\sum x_i = \frac{\sum x_i}{n} \quad , \tag{2}$$

where

$\bar{x}$ = the mean (sometimes called “x bar”),

x_i = the data point with index i,

n = the number of data points, and

$\sum$ = the summation symbol

$\rightarrow \sum_{i=1}^{n} x_i = x_1 + x_2 + x_3 + \cdots + x_n$.

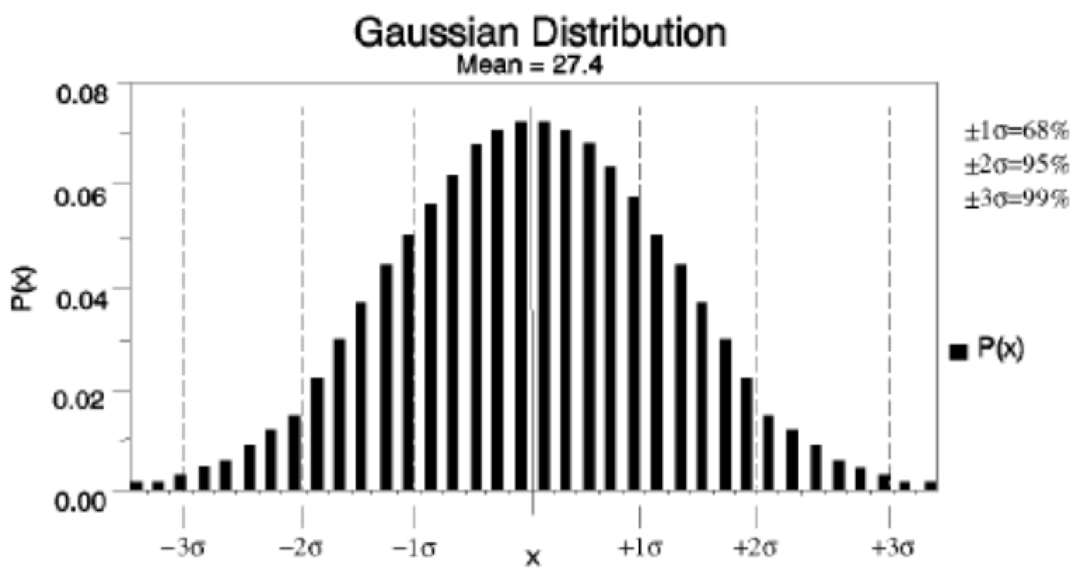
Variance and Standard Deviation

2.03.05 Define the following terms:

a. variance
b. standard deviation

Regarding the Gaussian distribution model shown in Figure 5, we need to define the terms “variance” and “standard deviation.” Both are used as descriptors of the spread of the population (or the data set) in a normal distribution.

Figure 5. Gaussian Distribution with Standard Deviation



Variance

The amount of scatter around the mean is defined as the sample variance or how much the data “vary” from the mean.

Standard Deviation

Mathematically, in a normal distribution, the standard deviation is the square root of the variance. More precisely, the variance is the standard deviation, as represented by *σ* (sigma) in Equation (3).

$$\sigma = \sqrt{\frac{\sum(x_i - \bar{x})^2}{(n-1)}} \ , \qquad (3)$$

where

σ = the standard deviation of a sample,

x_i = the sample counts for each data point,

$\bar{x}$ = the mean, and

n = the number of data points.

If most of the data points are located close to the mean, the curve will be tall and steep and have a small standard deviation. If the data points are scattered, the curve will be lower and not as steep and have a large standard deviation.

Gaussian Deviation

For Gaussian deviation,

- 68.2% of the area under the curve falls within ±1 standard deviation (1σ) of the mean,
- 95.4% of the area under the curve falls within ±2 standard deviations (2σ) of the mean, and
- 99.7% of the area under the curve falls within ±3 standard deviations (3σ) of the mean.

In terms of counting processes, if the distribution, as depicted in Figure 5, is representative of a counting function with a mean observable success >20 (Gaussian Distribution), then

- 68.2% of the time, the observed successes (counts) will be within ±1 standard deviation of the mean;
- 95.4% of the time, the observed successes (counts) will be within ±2 standard deviations of the mean; and
- 99.7% of the time, the observed successes (counts) will be within ±3 standard deviations of the mean.

The known statistical distribution is used in radiation protection when setting up a counting system and in evaluating its operation by means of daily preoperational source checks. In performing the calibration of the system, a radioactive source with a known activity is counted 20 times for 1 minute each time. Using the data from the 20 counts, the mean and standard deviation can be calculated. The mean can then be used to determine the efficiency of the system while allowing for a certain number of standard deviations during operation. The 20 counts can also be used to perform another required test of the system's performance: the Chi (pronounced “kye”)-squared test.

Calculating Standard Deviation

2.03.06 Given the formula and a set of data, calculate the standard deviation.

Example 2.03-1: Calculate the mean and sample standard deviation for the following data set using Equation (4):

193, 188, 202, 185, 179, 217, 191 199, 201, 214,

193, 232, 199, 210, 196, 211, 191, 203, 201, 195

$$\sigma = \sqrt{\frac{\sum(x_i - \bar{x})^2}{(n-1)}} \qquad (4)$$

Notes. . . .

Purpose of a Chi-Squared Test

2.03.07 State the purpose of a Chi-squared test.

The Chi-squared test is used to determine the precision of a counting system. Precision is a measure of exactly how a result is determined without regard to its accuracy; it is a measure of the reproducibility of a result or, in other words, how often that result can be repeated or how often a “success” can be obtained.

This test results in a numerical value, called the Chi-squared value (X^2), which is then compared with a range of values for a specified number of observations or trials. This range represents the 2 expected (or predicted) probability for the chosen distribution. If the X^2 value is lower than the expected range, this tells us that there is not a sufficient degree of randomness in the observed data. If the value is too high, it tells us that there is too much randomness in the observed data.

The Chi-squared test is often referred to as a "goodness-of-fit" test. If it does NOT fit a curve indicating sufficient randomness, then the counting instrument may be malfunctioning, as shown in Equation (5):

$$X^2 = \frac{\sum(x_i - \bar{x})^2}{\bar{x}} \qquad (5)$$

Calculating the Chi-Squared Value

Using the data from Example 2.03-1 (see 2.03.06, Calculating Standard Deviation), determine the Chi-squared value for the data set. If we assume that a given set of data passes the Chi-squared test, the data then can be used to prepare quality control charts for use in verifying the consistent performance of the counting system.

Notes. . . .

Criteria for Acceptable Chi-Squared Values

2.03.08 State the criteria for acceptable Chi-squared values at your site.

Most RCTs at LANL will not be expected to perform Chi-squared tests. When an RCT is tasked with performing Chi-squared tests, he or she receives facility-specific training or mentoring.

Notes. . . .

Quality Control (QC) Charts

2.03.09 State the purpose of creating quality control (QC) charts.

QC charts may be prepared using source counting data obtained during system calibration. Because this test verifies that the equipment is still operating within an expected range of response, we clearly cannot change the conditions of the test in midstream. QC charts, then, enable us to track the performance of the system while in use.

Data that can be used for quality control charts include gross counts, counts per unit time, and efficiency. Most nuclear laboratories use a set counting time corresponding to the normal counting time for the sample geometry being tested. When the system is calibrated and the initial calculations are performed, the numerical values of the mean ±1, 2, and 3 standard deviations are also determined.

Using graph paper or a computer graphing software, lines are drawn all the way across the paper at those points corresponding to the mean; the mean plus 1, 2, and 3 standard deviations; and the mean minus 1, 2, and 3 standard deviations. The daily control check results are then plotted on the control chart to see if the results fall outside the limits.

Notes. . . .

Maintenance and Review of QC Charts

2.03.10 State the requirements for maintenance and review of QC charts at your site.

Most RCTs at LANL will not be expected to maintain or review QC charts. When an RCT is tasked with maintaining and reviewing QC charts, he or she receives facility-specific training or mentoring.

Notes. . . .

Calculating Warning and Control Limits

2.03.11 State the purpose of calculating warning and control limits.

System Operating Limits

The values corresponding to ±2 and ±3 standard deviations may be called the upper and lower warning and control limits, respectively (or other terms, such as action limits). The results of the daily source counts are graphed in many count rooms. Most of the time, results will lie between the lines corresponding to ±1 standard deviation (68.2%). We also know that 95.4% of the time, our count will be within ±2 standard deviations and that 99.97% of the time, our count will be within ±3 standard deviations.

Counts that fall outside the warning limit (±2 σ) are not necessarily incorrect. Statistical distribution models say that we should get some counts in that area. Counts outside the warning limits indicate that something MAY be wrong. The same models say that we will also get some counts outside the control limits (±3 σ). However, not very many measurements will be outside those limits.

We use 3 σ as the control—a standard for acceptable performance. In doing so, we say that values outside of ±3 σ indicate unacceptable performance, even though those values may be statistically valid.

True randomness also requires that there be no patterns in the data that are obtained; some will be higher than the mean, some will be lower, and some will be right on the mean. When patterns do show up in quality control charts, they are usually indicators of systematic error. For example,

- multiple points outside 2 sigma;
- repetitive points (n out of n) outside 1 sigma;
- multiple points, in a row, on the same side of the mean; and
- multiple points, in a row, going up or down.

The assumption is made that systematic error is present in our measurements and that our statistical analysis has some potential for identifying its presence. However, industry assumption is that systematic error that is present is very small in comparison with random error.

Quality control charts should be maintained in the area of the radioactivity counting system so that they will be readily accessible to those who operate the system. These charts can then be used by operators to determine if routine, periodic checks (typically daily) have been completed before system use.

Determining Efficiencies and Correction Factors

2.03.12 State the purpose of determining efficiencies and correction factors.

Counter Efficiency

A detector intercepts and registers only a fraction of the total number of radiations emitted by a radioactive source. The major factors determining the fraction of radiations emitted by a source that are detected include the fraction

- of radiations emitted by the source that travel in the direction of the detector window,
- emitted in the direction of the detector window that actually reach the window,
- of radiations incident on the window that actually pass through the window and produce an interaction, and
- scattered into the detector window.

In principle, all radiation detectors will produce an output pulse for each particle or photon that interacts within its active volume.

Because of the factors outlined above, only a fraction of the disintegrations occurring in a source results in counts being reported by the detector. Therefore, only a certain fraction of the disintegrations occurring results in counts reported by the detector. Using a calibrated source with a known activity, a precise figure can be determined for this fraction. This value can then be used as a ratio to relate the number of pulses counted to the number of particles and/or photons emitted by the source. This ratio is called the efficiency. The detector efficiency gives us the fraction of counts per disintegration, or c/d.

Because activity is the number of disintegrations per unit time and the number of counts are detected in a finite time, the two rates can be used to determine the efficiency if both rates are in the same units of time. Counts per minute (cpm) and disintegrations per minute (dpm) are the most common.

Notes. . . .

Calculate Efficiencies and Correction Factors

2.03.13 Given the counting data and source assay information, calculate efficiencies and correction factors.

The efficiency, E, can be determined as shown in Equation (6) as

$$E = \frac{cpm}{dpm} = \frac{c}{d} \quad . \tag{6}$$

Used in this manner, the time units will cancel, resulting in c/d. The efficiency obtained in the formula above will be in fractional or decimal form. To calculate the percent efficiency, the fraction can be multiplied by 100. For example, an efficiency of 0.25 would mean 0.25 × 100, or 25%.

Calculate Efficiency

Example 2.03-3: A source is counted and yields 2840 cpm. If the source activity is known to be 12,500 dpm, calculate the efficiency and percent efficiency.

Calculating Activity

By algebraic manipulation, Equation (6) can be solved for the disintegration rate [see Equation (7)]. The system efficiency is determined as part of the calibration. When analyzing samples, a count rate is reported by the counting system.

Using Equation (7), the activity, (A), of the sample can be determined in dpm and then converted to any other units of activity (e.g., Ci or Bq).

$$dpm = \frac{cpm}{E} \rightarrow A_{dpm} = \frac{cpm}{E} \quad . \tag{7}$$

Example 2.03-4: A sample is counted on a system with a 30% efficiency. If the detector reports 4325 net cpm, what is the activity of the sample in dpm?

Calculating Correction Factors

A correction factor (CF), which is simply the inverse of the efficiency, is used by multiplying it by the net count rate to determine the activity, as in Equation (8):

$$CF = \frac{1}{E} \quad . \tag{8}$$

Example 2.03-5: An instrument has an efficiency of 18%. What is the correction factor?

Note: This count-rate correction factor should not be confused with a geometry correction factor used with some radiation instruments, such as the beta correction factor for a Cutie Pie (RO-3C).

Meaning of Counting Data Reported as x ± y

2.03.14 State the meaning of counting data reported as x ± y.

The error present in a measurement governed by a statistical model can be calculated using known parameters of that model. Nuclear laboratories are expected to operate at a high degree of precision and accuracy. However, because we know that our measurements contain some error, we are tasked with reporting measurements to outside agencies in a format that identifies that potential error.

Error Calculations

The format that is used should specify the activity units and a range in which the number must fall. In other words, the results would be reported as a given activity plus or minus the error in the measurement. Because nuclear laboratories prefer to be right more than they are wrong, counting results are usually reported in a range that would be correct 95% of the time, or at a 95% confidence level (CL).

To do this, the reported result should be in the format of Equation (9) as

$$x.xx \ \pm yy(K_{\sigma}) \quad , \tag{9}$$

where

x.xx = the measured activity, in units of dpm, Ci, or Bq;

yy = the associated potential (or possible) error in the measurement;

K = the multiple of counting error; and

σ = the standard deviation at a stated CL.

Note: The use of K σ is required only for CLs other than 68% (see Table 4). Therefore,

$\sigma = 1 \times \sigma$ 68% CL (optional),

$1.64\ \sigma = 1.64 \times \sigma$ 90% CL (sometimes used), and

$2\ \sigma = 1.96 \times \sigma$ 95% CL (normally used).

For example, a measurement of 150 ±34 dpm (2 σ) indicates the activity as 150 dpm; however, it could be as little as 116 dpm or as much as 184 dpm with 95% confidence (at 2 σ).

Results to Desired Confidence Level

2.03.15 Given the counting results and appropriate formulas, report results to desired confidence level.

The calculations of the actual range of error are based on the standard deviation for the distribution. In the normal (or Gaussian) distribution, the standard deviation of a single count is defined as the square root of the mean, or $\sigma = \sqrt{\bar{x}}$.

As shown in Table 4, the error, e, present in a single count, is some multiplier, K, multiplied by the square root of that mean (i.e., some multiple times the standard deviation, K σ). The value of K used is based on the CL that is desired and is derived from the area of the curve included at that CL (see Figure 5).

Table 4. Counting Error Multiples

Error	Confidence Level (%)	K
Probable	50	0.6745
Standard	68	1.0000
9/10	90	1.6449
95/100	95	1.9600
99/100	99	2.5750

To calculate the range to the point at which you would expect to be right 95% of the time, you would multiply the standard deviation by 1.96 and report the results of the measurement as x.xx dpm ±yy dpm (2 σ).

Note that using a 68% or 50% CL introduces an expected error a large percentage of the time. Therefore, for reasonable accuracy, a higher CL must be used.

The simple standard deviation (σ) of the single count (x) is usually determined as a count rate (counts per unit time) by dividing the count rate (R) by the count time (T). Subscripts can be applied to distinguish sample count rates from background count rates, as shown in Equation (10):

$$\sigma = K\sqrt{\frac{R}{T}} \qquad (10)$$

Example 2.03-6: The count rate for a sample was 250 cpm. Assume a 10-minute counting time, zero background counts, and a 25% efficiency. Report the sample activity at a 95% CL.

Purpose of Determining Background

2.03.16 State the purpose of determining background.

Radioactivity measurements cannot be made without considering the background. Background, or background radiation, is the radiation that enters the detector concurrently with the radiation emitted from the sample being analyzed.

This radiation can be from natural sources, either external to the detector (i.e., cosmic or terrestrial), or can originate inside the detector chamber that is not part of the sample.

In practice, the total counts are recorded by the counter. This total includes the counts contributed by both the sample and the background. Therefore, the contribution of the background will produce an error in radioactivity measurements, unless the background count rate is determined by a separate operation and subtracted from the total activity, or gross count rate.

The difference between the gross and the background rates is called the net count rate (sometimes given in units of corrected counts per minute, or ccpm).

This relationship is seen in Equation (11) as

$$R_S = R_{S+B} - R_B \quad , \tag{11}$$

where

R_S = the net sample count rate (in cpm),

R_{S+B} = the gross sample count rate (in cpm), and

R_B = the background count rate (in cpm).

The background is determined as part of the system calibration by counting a background (empty) sample holder for a given time.

The background count rate is determined in the same way as any count rate, where the gross counts are divided by the count time, as seen in Equation (12) as

$$R_B = \frac{N_B}{T_B} \quad , \tag{12}$$

where

R_B = the background count rate (counts per time, i.e., cpm);

N_B = the gross counts, background; and

T_B = the background count time.

In practice, background values should be kept as low as possible. As a guideline, background on automatic counting systems should not be allowed to exceed 0.5 cpm alpha and 1 cpm beta-gamma. If the system background is above this limit, the detector should be cleaned or replaced.

Reducing Background

Typically, the lower the system background, the more reliable the analysis of the samples will be. In low-background counting systems, the detector housing is surrounded by lead shielding to reduce the background. Nonetheless, some background still manages to reach the detector. Clearly, little can be done to reduce the actual source of background due to natural sources.

On many systems, a second detector is incorporated to detect penetrating background radiation. When a sample is analyzed, the counts detected by this second detector during the same time period are internally subtracted from the gross counts for the sample.

Background originating inside the detector chamber can be, for the most part, more easily controlled. The main contributors of this type of background are

- radiation emitted from detector materials,
- radioactive material found on inside detector surfaces,
- radioactive material found on the sample slide assembly, and
- contamination found in or on the sample planchet or planchet carrier.

Unfortunately, trace levels of radioactivity exist in the materials of which detectors and their housings are made: simply a fact of life in the atomic age. The contribution to background from such materials is negligible but should nonetheless be acknowledged.

Purpose of Determining Background

Radioactive material can be transferred from contaminated samples to the inside surfaces of the detector chamber during counting. This transfer usually occurs when samples having gross amounts of material on them are counted in a low-background system. During the insertion and withdrawal of the sample into the detector chamber, loose material can be spread into the chamber. To prevent this spread, these samples should be counted using a field survey instrument or a mini-scaler. Low-background systems are designed for counting lower-activity samples. Counting a high-activity sample on these systems should be avoided unless the sample is a sealed radioactive source.

Notes. . . .

Method and Requirements for Determining Background

2.03.17 State the method and requirements for determining background for counting systems at your site.

Methods and requirements for determining background are specified in RCT operational procedures.

Notes. . . .

Purpose of Performing Sample Planchet Maintenance

2.03.18 State the purpose of performing sample planchet maintenance.

Planchets and carriers should be inspected, cleaned, and counted on a routine basis. All in-use planchets and carriers must read less than the established site limits. Planchets exceeding these limits should be decontaminated and recounted as necessary.

By keeping planchets as clean and free from contamination as possible, sample result reliability will be increased because the amount of error introduced in the sample analysis will be reduced.

Notes. . . .

Planchet Maintenance for Counting Systems

2.03.19 State the method and requirements for performing planchet maintenance for counting systems at your site.

The methods and requirements for performing planchet maintenance for counting systems are specified in RCT operational procedures.

Propagation of Error

The error present in a measurement includes the error present in the sample count and the error present in the background count.

The total error in the measurement is calculated by squaring the error in the background, adding that to the square of the error in the sample count, and taking the square root of the sum, as shown in Equation (13).

$$e_S = \sqrt{e_{S+B}^2 + e_B^2} \quad ,$$

where

e_s = the error present in the measurement (sample),

e_{s+B} = the error in the sample count (sample plus background), and

e_b = the error present in the background count.

Equation (14):

$$K\sigma_S = K\sqrt{\frac{R_{S+B}}{T_S} + \frac{R_B}{T_B}} \qquad (14)$$

where

RS+B = the gross sample count rate (sample plus background),

RB = the background count rate,

T_S = the sample count time,

T_B = the background count time, and

K = the CL multiple (see Table 4).

The error in the sample count is the standard deviation of the count, which is the square root of that count [see Equation (13) above].

Example 2.03-7: An air sample is counted and yields 3500 counts for a 2-minute count period. The system background is 10 cpm, as determined over a 50-minute count time. Determine the error in the sample, and report the net count rate to a 95% CL.

If the sample counting time and the background counting time are the same, the formula can be simplified even more to Equation (15) as

$$K\sigma_S = K\sqrt{\frac{R_{S+B}+R_B}{T}} \quad . \qquad (15)$$

- Example 2.03-8: A long-lived sample is counted for 1 minute and gives a total of 562 counts. A 1-minute background gives 62 counts. Report the net sample count rate to a 95% CL.

Methods to Improve Statistical Validity of Sample Measurements

2.03.20 Explain methods to improve the statistical validity of sample measurements.

Minimizing the statistical error present in a single sample count is limited to several options. If we look at the factors present in the calculation below [as in Equation (14)], we can see that there are varying degrees of control over these factors.

The standard deviation in terms of count rate is

$$\sigma_{rate} = \sqrt{\frac{R_{S+B}}{T_S} + \frac{R_B}{T_B}} \ ,$$

where

R_{S+B} = the sample count rate.

- **We really have no control over this**.

  R_B is the background count rate.

- **We do have some control over this**.

  On any counting equipment, the background should be maintained as low as possible. However, in most of our counting applications, the relative magnitude of the background count rate should be extremely small in comparison with the sample count rate if proper procedures are followed. Size truly becomes an issue when we are counting samples for free release or environmental samples. However, **some reduction in error can be obtained by increasing the background counting time**, as discussed below.

  T_B and T_S are the background and sample count times.

- **These are the factors that we have absolute control over**.

In the previous section, we discussed the reliability of the count itself. We have been able to state that a count under given circumstances may be reproduced with a certain CL and that the larger the number of counts, the greater the reliability. The condition we have been assuming is that our count is taken within a given time. To get more precise results, many counts must be observed. Therefore, if we have low count rates, the counting time must be increased to obtain many counts, thereby making the result more precise (or reproducible).

Count Times

The total counting time required depends on both the sample and background count rates. For high sample activities, the sample count time can be relatively short compared with the background count time. For medium count rates, we must increase the sample count time to increase precision. As the sample activity gets even lower, we approach the case where we must devote equal time to the background and source counts.

In other words, by counting low activity samples for the same amount of time as that of the background, we increase the precision of our sample result. However, we must never count a sample for a period of time longer than the system background.

To summarize this section, by minimizing the potential error present, we improve the statistical validity of our measurements.

Detection Limits

2.03.21 Define "detection limit," and explain the purpose of using detection limit values for counting systems at your site.

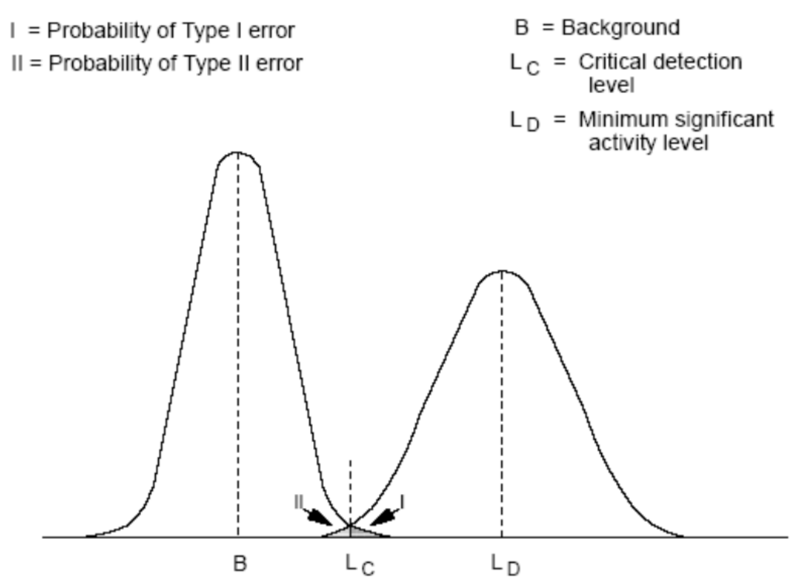
The *detection limit* of a measurement system refers to the statistically determined quantity of radioactive material (or radiation) that can be measured (or detected) at a preselected CL. This limit is a factor of both the instrumentation and the technique/procedure being used.

The two parameters of interest for a detector system with a background response greater than zero are L_C and L_D (see Figure 6).

- **L_C—Critical detection level**: the response level at which the detector output can be considered "above background."
- **L_D—Minimum significant activity level**: the activity level that can be seen with a detector with a fixed level of certainty.

The detection levels can be calculated by the use of Poisson statistics, assuming that random errors and systematic errors are separately accounted for and that there is a background response.

Figure 6. Errors in Detection Sensitivity



For these calculations, two types of statistical counting errors must be considered quantitatively to define acceptable probabilities for each type of error:

- **Type I** – occurs when a detector response is considered above background when in fact it is not (associated with LC).
- **Type II** – occurs when a detector response is considered to be background when in fact it is greater than background (associated with LD).

If the two probabilities (areas labeled I and II in Figure 6) are assumed to be equal and the background of the counting system is not well known, then the LC and LD can be calculated. The two values would be derived using the equations LC = $k\sigma_B$ and LD = $k^2 + 2k\sigma_B$, respectively.

If 5% false positives (Type I error) and 5% false negatives (Type II error) are selected to be acceptable levels, i.e., a 95% CL, then k = 1.645 and the two equations can be written as Equations (16) and (17):

$$L_C = 1.645\sqrt{\frac{R_B}{T_B} + \frac{R_B}{T_B}} \quad \text{and} \tag{16}$$

$$L_D = \frac{3}{T_S} + 3.29\sqrt{\frac{R_B}{T_B} + \frac{R_B}{T_B}} \ , \tag{17}$$

where

L_C = the critical detection level,

L_D = the *a priori* (before the fact) detection limit (minimum significant activity level),

R_B = the background count rate,

T_B = the background count time, and

T_S = the sample count time.

The minimum significant activity level, L_D, is the a *priori* activity level that an instrument can be expected to detect 95% of the time. In other words, it is the smallest amount of activity that can be detected at a 95% CL. When stating the detection capability of an instrument, this value should be used.

The critical detection level, L_C, is the lower bound on the 95% detection interval defined for L_D and is the level at which there is a 5% chance of calling a background value "greater than background." This value (L_C) should be used when actually counting samples or making direct radiation measurements. Any response above this level should be counted as positive and reported as valid data. This action will ensure 95% detection capability for L_D.

If the sample count time (T_s) is the same as the background count time (T_B), then Equations (16) and (17) can be simplified as Equations (18) and (19):

$$L_C = \sqrt{\frac{R_B}{T}} \quad \text{and} \qquad (18)$$

$$L_D = \frac{3}{T} + \sqrt{\frac{R_B}{T}} \quad , \qquad (19)$$

where

T = the count time for sample and background.

Therefore, the full equations for L_C and L_D must be used when the count times for the samples and background are different (when 95% CL is used).

These equations assume that the standard deviation of the sample planchet/carrier background during the sample count (where the planchet/carrier is assumed to be 0 activity) is equal to the standard deviation of the system background (determined using the background planchet/carrier).

The critical detection level, L_C, is used when reporting survey results; at a 95% CL, samples above this value are radioactive. This calculation then presupposes that 5% of the time, clean samples will be considered radioactive.

The minimum significant activity level, L_D, also referred to as the lower limit of detection (LLD) in some texts, is calculated before samples are counted. This value is used to determine minimum count times based on release limits and airborne radioactivity levels. In using this value, we are saying that at a 95% CL, samples counted for at least the minimum count time calculated using the LD that are positive will indeed be radioactive (above the L_c).

This calculation then presupposes that 5% of the time, samples considered clean will actually be radioactive.

Example 2.03-9

A background planchet is counted for 50 minutes and yields 16 counts. Calculate the critical detection level and the minimum significant activity level for a 0.5-minute sample count time.

Minimum Detectable Activity (MDA)

The minimum significant activity level, L_D, can be used to evaluate whether the measurement process is adequate to meet requirements.

For example, the results of Example 2.03-9 (in units of cpm) can be converted using counting efficiency and the area of the swipe to determine the adequacy of the measurement system for contamination surveys for removable contamination performed to ensure that the removable surface contamination values specified in Appendix D of 10 CFR 835 are not exceeded (in units of dpm/100 cm^2).

In most cases, swipes to determine the removable contamination levels will be counted in the field or submitted to the counting lab for analysis, where the background radiation levels are sufficiently low enough to ensure that L_D, and thus the MDA, are below the limits in 10 CFR 835 Appendix D.

$$MDA_{removable} = L_D \times \frac{100/A_{swipe}}{e} \quad , \tag{20}$$

where

$MDA_{removable}$ = the activity level in dpm/100 cm^2,

e = the detector efficiency in counts per disintegration, and

A_{swipe} = the area of the surface swiped in cm^2.

Static Count MDAs

Similarly, an MDA can be calculated for a static field measurement to evaluate total surface contamination values. In this case, an adjustment is needed to account for the size of the detector. To determine the MDA for static counts, the probe is stationary for a prescribed period of time, and Equation (21) is used.

$$MDA_{total} = L_D \times \frac{100/A_{swipe}}{e} \quad , \tag{21}$$

where

MDA_{total} = the activity level in dpm/100 cm^2,

e = the detector efficiency in counts per disintegration, and

A_{probe} = the surface area of the probe in cm^2.

Scanning MDAs

The ability to identify a small region or area of slightly elevated radiation during surface scanning is dependent on the RCT's skill in recognizing an increase in the audible output of the instrument. Experience has shown that a 25% to 50% increase may be easily identifiable at ambient background levels of several thousand counts per minute, whereas at ambient levels of a few counts per minute, a two- to three-fold increase in the audible signal is required before a change is readily recognizable.

The detection sensitivity of scanning is dependent on many other factors, such as detector scan speed, surface characteristics, size of elevated activity region, surveyor efficiency, level of activity, and detector/surface distance. The ability to detect an elevated region of activity using a particular survey scanning technique would need to be determined empirically and is beyond the scope of this training.

Notes. . . .

Calculate Detection Limit Values for Counting Systems

2.03.22 Given the formula and necessary information, calculate detection limit values for counting systems at your site.

LANL uses the following standard MDA formula:

$$MDA = \frac{2.71 + 3.29\sqrt{R_B T_S \left(1 + \frac{T_S}{T_B}\right)}}{Eff \times T_S} \quad ,$$

where

R_B = the background count rate in cpm,

T_S = the sample count time in seconds,

T_B = the background count time in seconds, and

Eff = the detector efficiency.

Important! If an instrument reads in dpm, R_B must be converted to cpm before plugging into this formula.

Notes. . . .

Determining Crosstalk

2.03.23 State the purpose and method of determining crosstalk.

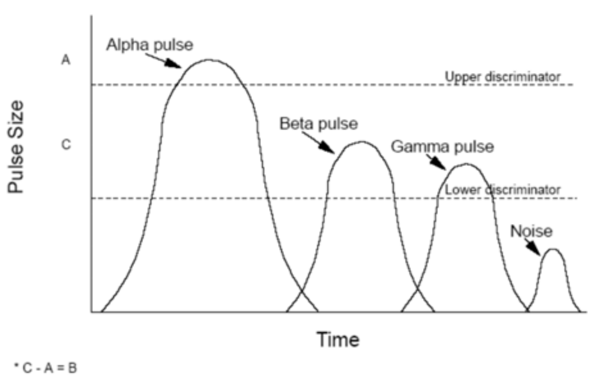
Discrimination

Crosstalk is a phenomenon that occurs on proportional counting systems (such as a Tennelec) that use electronic, pulse-height discrimination, thereby allowing the simultaneous analysis for alpha and beta-gamma activity.

Discrimination is accomplished by establishing two thresholds, or windows, which can be set in accordance with the radiation energies of the nuclides of concern. Recall that the pulses generated by alpha radiation will be much larger than those generated by beta or gamma. This difference in pulse height makes the discrimination between alpha and beta-gamma possible.

Beta and gamma events are difficult to distinguish; thus, they are considered as one by such counting systems. In practice, the lower window is set such that electronic noise and ultra-low-energy photon events are filtered out. Any pulse generated that has a size greater than the setting for the lower window is considered an event, or a count. The upper window is then set such that any pulses that surpass the upper discriminator setting will be considered an alpha count (see Figure 7).

Figure 7. Pulse-Height Discrimination



For output purposes, the system routes each count to a series of channels, which simply keep a total of the counts routed to them. Channel A is for alpha counts, Channel B is for beta-gamma counts, and Channel C is for total counts. As a sample is being counted, all valid counts registered (i.e., those which surpass the lower discriminator setting) are routed to the C channel.

In addition, if the count was considered an alpha count (i.e., it surpassed the upper-discriminator setting) it is routed to the A channel; otherwise, it is tallied in the B channel. In effect, the number of beta-gamma counts (Channel B) are determined by subtracting the number of alpha counts (Channel A) from the total counts (Channel C), or B = C - A.

Origin of Crosstalk

Now that we understand the process involved, a dilemma stems from the fact that events are identified by the system as either alpha or beta-gamma, according to the size of the pulse generated inside the detector. The system cannot really tell what type of radiation has generated the pulse. Rather, the pulse is labeled as “alpha” or “beta-gamma” by comparing the size of the pulse with the discriminator setting. The setting of the discriminator poses the dilemma.

Alpha particles entering the detector chamber are generally attenuated by the detector fill gas because of their high LET (**linear energy transfer)**, thereby producing a large pulse. Low-energy beta particles and photons will also lose all their energy within the detector gas, but nevertheless produce a smaller pulse because of their lower energies. High-energy beta particles can still retain some of their energy, even after having produced a pulse while traversing the detector volume.

Rather than leaving the detector, as would a photon, the beta is reflected off of the detector wall and reenters the volume of gas, causing ionizations and generating a second pulse. These two pulses can be so close together that the detector sees them as one large pulse. Because of the large pulse size, it can surpass the upper discriminator setting and is therefore counted as an alpha and not as a beta.

The result is that alpha activity can be reported for a sample when in fact little or no alpha was present. Conversely, if a true alpha-generated pulse is not large enough to exceed the upper discriminator, it would be counted as a beta-gamma event. This is *crosstalk.*

The solution is not simple. The setting of the upper discriminator depends on the radiations and energies of the sources and samples being analyzed. If high-energy beta radiations are involved, a significant portion of them could be counted as alpha events if the setting is too low. If the setting is too high, lower-energy alpha events could be counted as beta-gamma. Typically, the setting of the discriminator will usually be some “happy medium.” A discussion of how this can be dealt with follows.

Calibration Sources and Crosstalk

For calibrations of Tennelec counting systems, the manufacturer provides the following general recommendations for discriminator settings:

1. Using an Sr-90 beta source, set the upper (A) discriminator such that there is 1% beta-to-alpha crosstalk.

2. Using a polonium (Po)-210 alpha source, set the A+B discriminator such that there is less than 3% alpha-to-beta crosstalk.

Energies of sources used to calibrate counting systems should be the same as, or as close as possible to the energies of radionuclides in the samples analyzed. Wherever possible, they should be a pure emitter of the radiation of concern.

Sr-90:

For beta-gamma sources, the most popular isotope in radiation protection is Sr-90. This isotope has a relatively long half-life of 29.1 years but emits betas of only 546 keV. However, Sr-90 decays to yttrium (Y)-90, another beta emitter that has a short half-life of only 2.67 days and emits a 2.281-MeV beta.

Yttrium-90 decays to zirconium (Zr)-90m, which emits a 2.186-MeV gamma almost instantaneously to become stable. The daughters reach equilibrium with the strontium parent within a number of hours after source assay. Therefore, for every Sr beta emitted, a Y beta is also emitted, thereby doubling the activity.

These sources are often listed as Sr/Y-90 for evident reasons.

This fact makes Sr/Y-90 sources an excellent choice, and they are used by many sites for calibrations and performance testing.

Po-210:

Polonium-210 is essentially a pure alpha emitter, which is primarily why it is recommended for calibrations and performance testing. This isotope yields a strong alpha, but it also has a short half-life. A comparison of some alpha emitters is given in Table 5.

Table 5. Alpha Emitters

Isotope	Half-Life	Energy (MeV)
Po-210	138.38 days	5.3044
Pu-239	2.4×10^4 years	5.156, 5.143, 5.105
Ra-226	1.60×10^3 years	4.78, 4.602
Th-230	7.54×10^4 years	4.688, 4.621
Natural U	4.4×10^9 years (avg.)	4.2 (avg.)

Notes. . . .

Acceptable Values of Crosstalk for Counting Systems

> 2.03.24 State the criteria for acceptable values of crosstalk for counting systems at your site.

The alpha-to-beta crosstalk must be less than 50%.

The beta-to-alpha crosstalk must be less than 10%.

Notes. . . .

Voltage Plateaus

2.03.25 State the purpose of performing a voltage plateau.

Very simply put, a voltage plateau is a graph that indicates a detector's response to a specific energy particle with variations of high voltage. The x axis represents the high voltage, and the y axis represents the response (i.e., counts). The resulting curve gives an indication of detector quality and can indicate any problems with the counting gas. The curve can also be used to determine the optimum operating high voltage for the system.

Most automatic low-background counting systems provide several different analysis modes. These modes count samples at certain predetermined voltages.

Counting systems generally provide three analysis modes:

- ALPHA ONLY,
- ALPHA THEN BETA, and
- ALPHA AND BETA (SIMULTANEOUS).

Two voltage settings usually are used in conjunction with these analysis modes:

- alpha voltage (lower) and
- (alpha plus) Beta voltage (higher).

Recall that in a proportional counter the amount of voltage determines the amount of gas multiplication. Because of the high LET of alpha radiation, at a lower voltage, even though the gas amplification will be lower, alpha pulses will still surpass the lower discriminator, and some will even pass the upper discriminator.

Because of the lower gas amplification, beta-gamma pulses will not be large enough to be seen. Therefore, any counts reported for the sample will be alpha counts.

In the ALPHA ONLY mode, the sample is counted once, at the alpha voltage.

Counts may appear in either the A or B channels.

Upon output, the A and B channels will be added together and placed in Channel A and therefore reported as alpha counts; the B channel will be cleared to zero, thereby resulting in no beta-gamma counts.

In the ALPHA THEN BETA mode, the sample is counted twice. The first count interval determines the alpha counts using the alpha voltage. The second count is done at the beta voltage. The determination of alpha and beta-gamma counts in this mode is based strictly on the operating characteristics of the detector at the different voltages. Thus, the A and B counts are summed during both counting intervals to attain the total counts.

The separation of alpha and beta-gamma counts is then calculated and reported according to Formula (20) as

$$\alpha = \frac{A_1 + B_1}{CF_\alpha} \cdots\cdots \beta = (A_2 - B_2) - \alpha \quad ,$$

where

α = the reported gross alpha counts;

β = the reported gross beta-gamma counts;

A_1, B_1 = the accumulated channel counts, respectively, first interval;

A_2,B_2 = the accumulated channel counts, respectively, second interval; and

CF_α = the alpha correction factor (ratio of alpha efficiency at alpha voltage to efficiency at beta voltage).

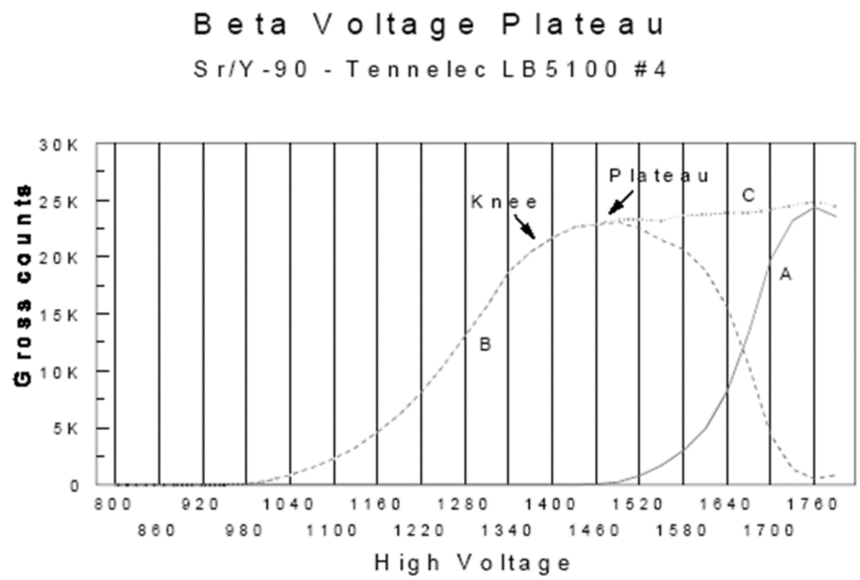
In the ALPHA AND BETA (SIMULTANEOUS) mode, the sample is counted once using the beta voltage. Alpha events are reported in the A channel, whereas beta-gamma counts are reported in the B channel. This mode is used most often.

As can be seen, the setting of the two voltages will have a direct impact on the number of counts reported for a given sample. The determination of what these voltage settings should be must be done such that the optimum performance of the detector is obtained for those voltage regions. This determination is the purpose of a plateau.

Method of Performing a Voltage Plateau on Counting Systems

2.03.26 State the method of performing a voltage plateau on counting systems at your site.

RCTs are not expected to perform voltage plateaus at LANL.



In conjunction with initial system setup and calibration by the vendor, two voltages plateaus are performed—alpha voltage and beta voltage. For P-10 gas, the alpha plateau is started at about 400 V and the beta plateau at about 900 V. The plateaus are developed by plotting the gross counts accumulated for each radionuclide.

Each time a count is completed, the high voltage is incremented a specific amount, typically 25 to 50 V, and another count is accumulated. This process is repeated until the end of the range is reached, typically about 1800 V. With the high voltage set at the starting point, few or no counts are observed because of insufficient ion production within the detector. As the voltage is increased, a greater number of pulses is produced with sufficient amplitude to exceed the discriminator threshold; these pulses are then accumulated in the counter.

There will be a high voltage setting where the increase in counts levels off (see Figure 8). This area is the detector plateau. Further increases in high voltage result in little change in the overall count rate.

The plateau should remain flat for at least 200 V using an Sr/Y-90 source, which indicates the plateau length. Between 1750 and 1850 V, the count rate will start to increase dramatically. This is the avalanche region, and the high voltage should not be increased any further.

The region where the counts level off is called the knee of the plateau. The operating voltage is chosen by viewing the plateau curve and selecting a point 50 to 75 V above the knee and where the slope per 100 V is less than 2.5%. This action ensures that minor changes in high voltage will have negligible effects on the sample count.

Poor counting gas or separation of the methane and argon in P-10 can result in a very high slope of the plateau. Upon initial system setup and calibration, the vendor determines and sets the optimum operating voltages for the system.

Thereafter, plateaus should be generated each time the counting gas is changed.

RCT: Module 2.03, Counting Errors and Statistics

Course 8768

April 2017

RCT_2.03_CountErrStats_8768_SM,R2.0

UNCLASSIFIED

Overview of Lesson

Radiological sample analysis involves observation of a random process that may or may not occur and an estimation of the amount of radioactive material present based on that observation. Across the country, radiological control personnel are using the activity measurements to make decisions that may affect the health and safety of workers at those facilities and their surrounding environments.

This course will present an overview of measurement processes, a statistical evaluation of both measurements and equipment performance, and some actions to take to minimize the sources of error in count room operations.

Objectives

2.03.01 Identify five general types of errors that can occur when analyzing radioactive samples, and describe the effect of each source of error on sample measurements.

2.03.02 State two applications of counting statistics in sample analysis.

2.03.03 Define the following terms:

a. mode

b. median

c. mean

Objectives

2.03.04 Given a series of data, determine the mode, median, or mean.

2.03.05 Define the following terms:

a. variance

b. standard deviation

2.03.06 Given the formula and a set of data, calculate the standard deviation.

2.03.07 State the purpose of a Chi-squared test.

2.03.08 State the criteria for acceptable Chi-squared values at LANL.

Objectives

2.03.09 State the purpose of creating quality control (QC) charts.

2.03.10 State the requirements for maintenance and review of QC charts at LANL.

2.03.11 State the purpose of calculating warning and control limits.

2.03.12 State the purpose of determining efficiencies and correction factors.

2.03.13 Given counting data and source assay information, calculate efficiencies and correction factors.

Objectives

2.03.14 State the meaning of counting data reported as x ± y.

2.03.15 Given counting results and appropriate formulas, report results to desired confidence level.

2.03.16 State the purpose of determining background.

2.03.17 State the method and requirements for determining background for LANL counting systems.

2.03.18 State the purpose of performing sample planchet maintenance.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

Objectives

2.03.19 State the method and requirements for performing planchet maintenance for LANL counting systems.

2.03.20 Explain methods to improve the statistical validity of sample measurements.

2.03.21 Define "detection limit," and explain the purpose of using detection limits in the analysis of radioactive samples.

2.03.22 Given the formula and necessary information, calculate detection limit values for LANL counting systems.

Objectives

2.03.23 State the purpose and method of determining crosstalk.

2.03.24 State the criteria for acceptable values of crosstalk for LANL counting systems.

2.03.25 State the purpose of performing a voltage plateau.

2.03.26 State the method of performing a voltage plateau on LANL counting systems.

2.03.01 - General Types (Sources) of Errors

Five general sources of error associated with counting a sample, assuming the counting system is calibrated correctly, are

1. Self-absorption
2. Backscatter
3. Resolving time
4. Geometry
5. The random disintegration of radioactive atoms (statistical variations).

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Self-Absorption

- When a sample has an abnormally large amount of material on the sample media (or the sample itself is large), it could introduce a counting error due to self-absorption, which is the absorption of the emitted radiation by the sample material itself. Self-absorption could occur for
    - Liquid samples with a high solid content or
    - Air samples from a high dust area

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Self-Absorption *(continued)*

- The use of improper filter paper may introduce a type of self-absorption, especially in alpha counting (i.e., absorption by the media, or filter).
- When counting samples, ensure that the correct sample medium is used and that the sample does not become too heavily loaded with sample material.
- Count room personnel should routinely check samples for improper media or heavily loaded samples.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Backscatter

- Counting errors due to backscatter occur when the emitted radiation traveling away from the detector is reflected, or scattered back, to the detector by the material in back of the sample.
- The amount of radiation that is scattered back will depend on the type and energy of the radiation and the type of backing material (reflector).
- The amount of backscattered radiation increases as the energy of the radiation increases and as the atomic number of the backing material increases.

2.03.01 - General Types (Sources) of Errors

Backscatter *(continued)*

- Generally, backscatter error is a consideration only for particulate radiation, such as alpha and beta particles.
- Because beta particles are more penetrating than alpha particles, backscatter error will be more pronounced for beta radiation.
- The ratio of measured activity of a beta source counted with a reflector compared with the count of the same source without a reflector is called the backscatter factor (BF).

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Backscatter *(continued)*

$$BF = \frac{counts\ with\ reflector}{counts\ without\ reflector}$$

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Backscatter *(continued)*

- Normally, backscatter error is accounted for in the efficiency or conversion factor of the instrument.
- However, if different reflector materials, such as aluminum and stainless steel, are used in calibration and operation, an additional unaccounted error is introduced.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Backscatter *(continued)*

- (This additional error will be about 6% for stainless steel vs aluminum.) Count room personnel must be aware of the reflector material used during calibration of the counting equipment.
- Any deviation from that reflector material will introduce an unaccounted error and reduce confidence in the analysis results.

2.03.01 - General Types (Sources) of Errors

Resolving Time

- Resolving time (or dead time) is the time interval that must elapse after a detector pulse is counted before another pulse can be counted.
- Any radiation entering the detector during the resolving time will not be recorded as a pulse; therefore, the information on that radiation interaction is lost.
- As the activity, or decay rate, of the sample increases, the amount of information lost during the resolving time of the detector is increased.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA
Los Alamos NATIONAL LABORATORY EST.1943

2.03.01 - General Types (Sources) of Errors

Resolving Time *(continued)*

- As the losses from resolving time increase, an additional error in the measurement is introduced. Typical resolving time losses are shown in Table 1.
- *Note: The total time required for the GM tube to give the maximum pulse height pulses is the recovery time.*

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Resolving Time *(continued)*

Table 1. Typical Resolving Time Losses

Count rate (cpm)	GM Tube [1]	Proportional [2]	Scintillation [3]
20,000	1.7%	< 1%	< 1%
40,000	3.3%	< 1%	< 1%
60,000	5.0%	< 1%	< 1%
100,000	8.3%	< 1%	1.0%
300,000	25.0%	< 1%	3.5%
500,000	42.0%	1.5%	5.8%

[1] GM tube: 50μs resolving time
[2] Proportional detector: 2μs resolving time
[3] Scintillation detector: 7μs resolving time

2.03.01 - General Types (Sources) of Errors

Resolving Time *(continued)*

- Resolving time losses can be corrected by using the equation:
- $R = \frac{R_0}{1 - R_0\tau}$,
- where
  - R = the “true” count rate, in cpm
  - R_0 = the observed count rate, in cpm
  - τ = the resolving time of the detector, in minutes (“tau”)

2.03.01 - General Types (Sources) of Errors

Resolving Time *(continued)*

- Count room personnel should be aware of the limitations for sample count rate, based on procedures and the type of detector in use, to prevent the introduction of additional resolving time losses.
- This is especially true for counting equipment that uses GM detectors.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Geometry

- Geometry-related counting errors result from the positioning of the sample in relation to the detector.
- Normally, only a fraction of the radiation emitted by a sample is emitted in the direction of the detector because the detector does not surround the sample.
- If the distance between the sample and the detector is varied, then the fraction of emitted radiation that hits the detector will change.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Geometry *(continued)*

- This fraction will also change if the orientation of the sample under the detector (i.e., side-to-side) is varied.
- An error in the measurement can be introduced if the geometry of the sample and detector is varied from the geometry used during instrument calibration.
- This variation is especially critical for alpha counting, where any change in the sample-to-detector distance also increases (or decreases) the chance of attenuation of the alpha particles by the air between the sample and detector.

2.03.01 - General Types (Sources) of Errors

Geometry *(continued)* – Common geometry-related errors

- Placing piling smears and/or filters on top of each other in the same sample holder (moves the top sample closer to the detector and varies the calibration geometry).
- Using deeper or shallower sample holders than those used during calibration (changes the sample-to-detector distance).
- Adjusting movable bases in the counting equipment sliding drawer (which changes the sample-to-detector distance).

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA
NNSA National Nuclear Security Administration
Los Alamos NATIONAL LABORATORY EST.1943

2.03.01 - General Types (Sources) of Errors

Geometry *(continued)* – Common geometry-related errors

- Using too many or inappropriate sample holders or planchets (which changes the sample-to-detector distance).
- Not fixing sources in position can change geometry and reduce reproducibility.
- Improperly setting Plexiglass shelving in the counting chamber.

2.03.01 - General Types (Sources) of Errors

Random Disintegration

- The fifth source of general counting error is the random disintegration of the radioactive atoms.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration - Statistics

- Statistics is a branch of mathematics that deals with the organization, analysis, collection, and interpretation of statistical data.
- No definition of statistical data is available.
- However, Webster's does define a statistic as “an estimate of a variable, as an average or a mean, made on the basis of a sample taken from a larger set of data.”

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*

- This last definition is applicable to our discussion of counting statistics.
- When we take samples, we use the data derived from analysis of those samples to make determinations about conditions in an area, in water, in air, etc., assuming that the sample is representative.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*

- Therefore, we have estimated conditions (a variable) on the basis of a sample (our smear, water sample, or air sample) taken from a larger set of data.
- Over the years, various methods and observations have identified three models that can be applied to observations of events that have two possible outcomes (binary processes).
- Fortunately, we can define most observations in terms of two possible outcomes.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*

- For example, look at Table 2:

Table 2. Probabilities of Success

Trial	Definition of Success	Probability of Success
Tossing a coin	"heads"	1/2
Rolling a die	"a six"	1/6
Observing a given radioactive nucleus for a time, t	The nucleus decays during the observation	$1-e^{-\lambda t}$

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*

- For each of the processes that we want to study, we have defined a trial (our test), defined a success and a failure (two possible outcomes), and determined the probability of observing our defined success.
- To study these processes, we can use proven, statistical models to evaluate our observations for error. Consider the possibilities when throwing two dice.
- As indicated in Table 3, 36 outcomes are possible when throwing 2 dice.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*

Table 3. Possibilities in Rolling Dice

Result	Possibilities	No. of Possibilities
2	1&1	1
3	1&2, 2&1	2
4	1&3, 2&2, 3&1	3
5	1&4 ,2&3, 4&1, 3&2	4
6	1&5, 2&4 ,3&3, 4&2, 5&1	5
7	1&6, 2&5, 3&4, 4&3, 5&2, 6&1	6
8	2&6, 3&5, 4&4, 5&3, 6&2	5
9	3&6, 4&5, 5&4 ,6&3	4
10	4&6, 5&5, 6&4	3
11	5&6 ,6&5	2
12	6&6	1

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*

- In our study of this process, if we define a success as throwing a number between 2 and 12, the outcome is academic.
- All trials will be successful, and we can describe the probabilities that throwing any individual number between the range of 2 and 12 inclusive would add up to 1.

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*

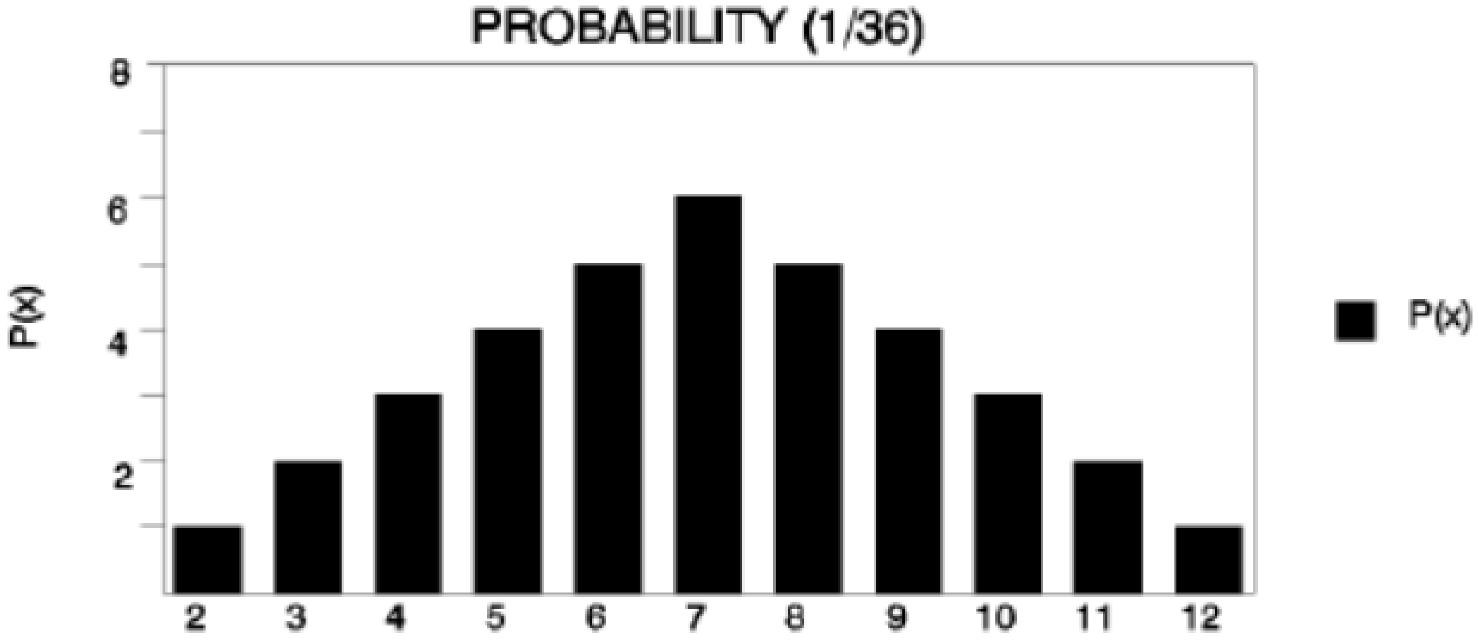
- If we define a success as throwing a particular number, we can define the probability of our success in terms of the number of possible outcomes that would give us that number in comparison with the total number of possible outcomes.
- If we were to take two dice, roll the dice a large number of times, and graph the results in the same manner, we would expect these results to produce a curve such as the one shown in Figure 1.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*

Figure 1. Probability in Binary Process



Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*

- The area under the curve can be mathematically determined and would correspond to the probability of success of a particular outcome.
- For example, to determine the probability of throwing a particular number between 2 and 12 we would calculate the area under the curve between 2 and 12.
- The result of that calculation is 36.

National Nuclear Security Administration
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA
Los Alamos NATIONAL LABORATORY EST. 1943

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*

- This is what statistics is all about; random binomial processes that should produce results in certain patterns that have been proven over the years. The three models that are used are distribution functions of binomial processes with different governing parameters.
- These functions and their restrictions are:
  - Binomial Distribution
  - Poisson Distribution

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*;
Binomial Distribution

- This distribution is the most general of the statistical models and is widely applicable to all processes with a constant probability.
- However, it is not widely used in nuclear applications because the mathematics are too complex.

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*;
Poisson Distribution

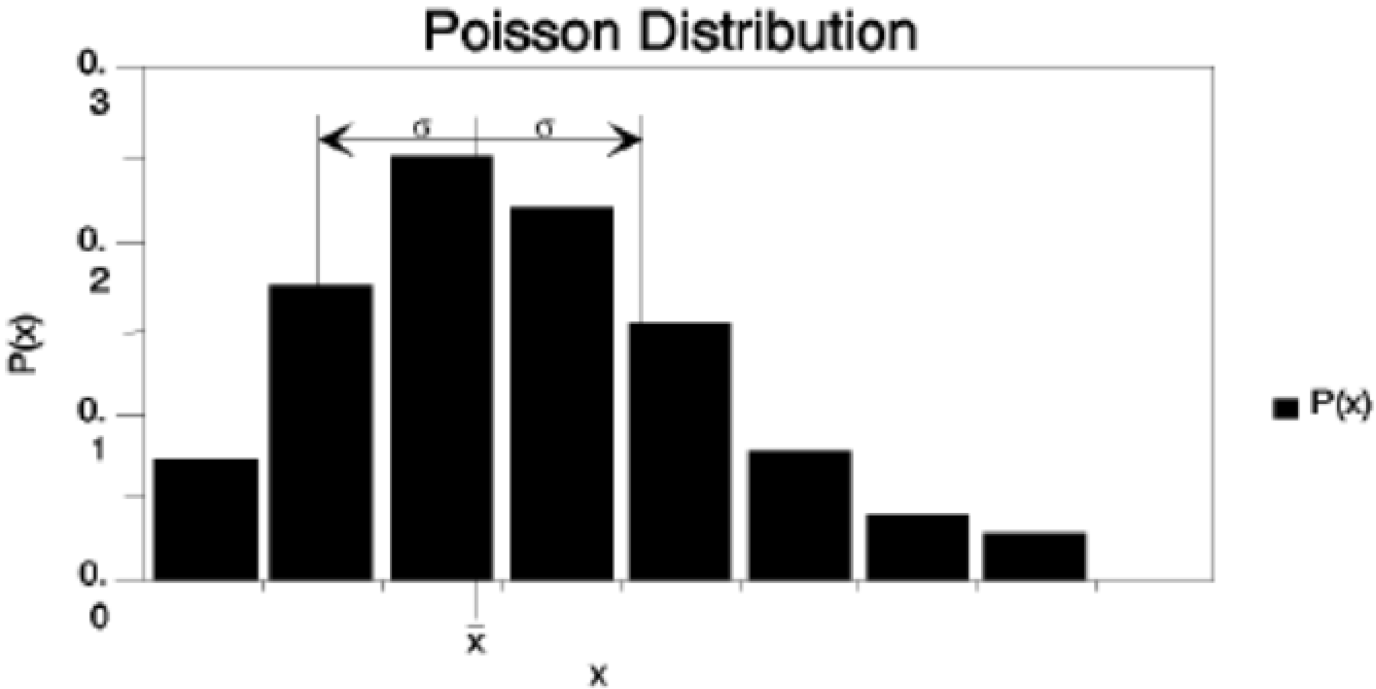
- A simplified version of binomial distribution is the Poisson (pronounced "pwusówn") distribution, which is **valid when the probability of success, P(x), is small**.
- If we graphed a Poisson distribution function, we would expect to see the predicted number of successes at the lower end of the curve, with successes over the entire range if sufficient trials were attempted.
- Thus, the curve would appear as seen in Figure 2.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*;
Poisson Distribution *(continued)*

Figure 2. Predicted Successes for Poisson



Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*; Poisson Distribution *(continued)*

- The Poisson model is used mainly for applications involving counting system background and detection limits, where the population (i.e., number of counts) is small.
- We will discuss this model in greater detail later.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*; Gaussian Distribution

- Also called the “normal distribution,” the Gaussian (pronounced “Gowziun”) distribution is a further simplification that is **applicable if the average number of successes is relatively large, but the probability of success is still low**.
- A graph of a Gaussian distribution function is shown in Figure 3.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*;
Gaussian Distribution *(continued)*

Figure 3. Predicted Successes for Gaussian Distribution

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*; Gaussian Distribution *(continued)*

- Note that the highest number of successes is at the center of the curve, the curve is bell shaped, and the relative change in success from one point to the adjacent one is small.
- Also note that the mean, or average number of successes, is at the highest point, or at the center of the curve.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.01 - General Types (Sources) of Errors

Random Disintegration – Statistics *(continued)*;
Gaussian Distribution *(continued)*

- The Gaussian, or normal, distribution is applied to counting applications where the mean count or success is expected to be greater than 20.
- It is used for counting system calibrations and operational checks, as well as for normal samples containing activity.
- It may or may not include environmental samples (i.e., samples with very low activity).

2.03.02 – Applications of Counting Statistics in Sample Analysis

Two purposes for statistical analysis of count room operations are

- Predict the inherent statistical uncertainty associated with a single measurement, thus allowing us to estimate the precision associated with that measurement.
- Serve as a check on the normal function of nuclear counting equipment.

Application of specific statistical methods and models to nuclear counting operations is termed **counting statistics** and is essentially used to do two things.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.03 – Mode, Median, Mean

Mode – An individual data point that is repeated the most in a particular data set.

Median – The center value in a data set arranged in ascending order.

Mean – The average value of all the values in a data set.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.04 - Given a Series of Data, Determine the Mode, Median, or Mean

Figure 4. Sample Data Set

Student	Test Score
Susan	80
Richard	82
Greg	86
Peter	88
Andrew	90
Wanda	92
Randy	95
Jennifer	95
Sarah	95

2.03.04 - Given a Series of Data, Determine the Mode, Median, or Mean

Determine the mode

- In the set of test scores shown in Figure 4, a score of 95 occurs (i.e., is repeated) more often than any other score. This score is the mode.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.04 - Given a Series of Data, Determine the Mode, Median, or Mean

Determine the median

- In the same set of test scores, the median is the score in the middle – where one half of the scores are below, and the other half are above the median.
- The median for the test scores in Figure 4 is 90.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.04 - Given a Series of Data, Determine the Mode, Median, or Mean

Determine the mean

- The mean is found by adding all of the values in the set together, and dividing by the number of values in the set.
- The mean of the nine test scores is 89.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.04 - Given a Series of Data, Determine the Mode, Median, or Mean

Equation of the mean

- The mean is often expressed using special symbols:

$$\bar{x} \sum x_i = \frac{\sum x_i}{n}$$

- Where
  - $\bar{x}$ = the mean (sometimes called "x bar")
  - x_i = the data point with index i
  - n = the number of data points
  - $\sum$ = the summation symbol

    $\rightarrow \sum_{i=1}^{n} x_i = x_1 + x_2 + x_3 + \cdots + x_n$

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.05 - Variance and Standard Deviation

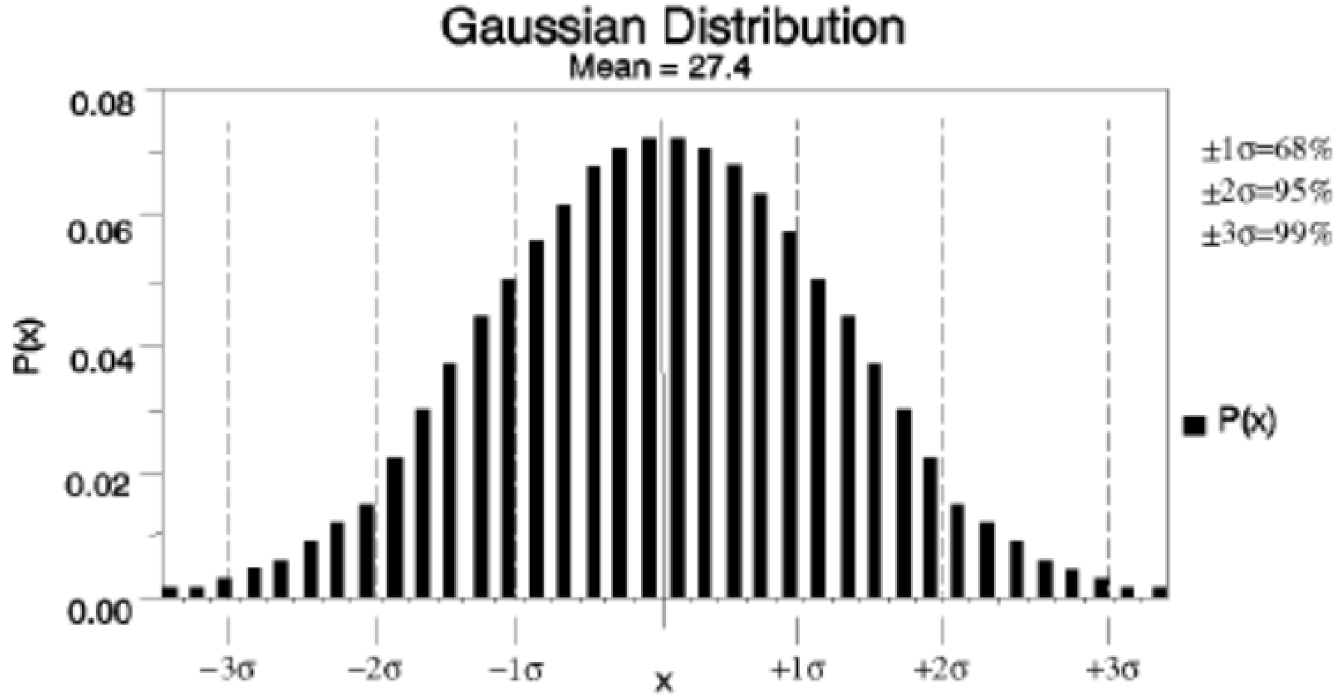
Regarding the Gaussian distribution model shown in Figure 5,

- We need to define the terms “variance” and “standard deviation”
- Both are used as descriptors of the spread of the population (or the data set) in a normal distribution

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.05 - Variance and Standard Deviation

Figure 5. Gaussian Distribution with Standard Deviation



Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.05 - Variance and Standard Deviation

Variance

- **The amount of scatter around the mean** is defined as the sample variance or
- how much the data “vary” from the mean.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.05 - Variance and Standard Deviation

Standard Deviation

- Mathematically, in a normal distribution, the standard deviation is the square root of the variance.
- More precisely, the variance is the standard deviation, as represented by σ (sigma).

$$\sigma = \sqrt{\frac{\sum(x_i - \bar{x})^2}{(n-1)}}$$

- Where
  - σ = the standard deviation of a sample
  - x_i = the sample counts for each data point
  - $\bar{x}$ = the mean
  - n = the number of data points

2.03.05 - Variance and Standard Deviation

Standard Deviation

- If most of the data points are located close to the mean, the curve will be tall and steep and have a small standard deviation.
- If the data points are scattered, the curve will be lower and not as steep and have a large standard deviation.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.05 - Variance and Standard Deviation

Gaussian Distribution

- 68.2% of the area under the curve falls within ±1 standard deviation (1σ) of the mean
- 95.4% of the area under the curve falls within ±2 standard deviations (2σ) of the mean
- 99.7% of the area under the curve falls within ±3 standard deviations (3σ) of the mean

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.05 - Variance and Standard Deviation

Gaussian Distribution *(continued)*

- In terms of counting processes, if the distribution, as depicted in Figure 5, is representative of a counting function with a mean observable success > 20 (Gaussian Distribution), then
  - 68.2% of the time, the observed successes (counts) will be within ± 1 standard deviation of the mean
  - 95.4% of the time, the observed successes (counts) will be within ± 2 standard deviations of the mean
  - 99.7% of the time, the observed successes (counts) will be within ± 3 standard deviations of the mean

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.05 - Variance and Standard Deviation

Gaussian Distribution *(continued)*

- The known statistical distribution is used in radiation protection when setting up a counting system and in evaluating its operation by means of daily pre-operational source checks.
- In performing the calibration of the system, a radioactive source with a known activity is counted 20 times for 1 minute each time.
- Using the data from the 20 counts, the mean and standard deviation can be calculated.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.05 - Variance and Standard Deviation

Gaussian Distribution *(continued)*

- The mean can then be used to determine the efficiency of the system while allowing for a certain number of standard deviations during operation.
- The 20 counts can also be used to perform another required test of the system's performance, the Chi (pronounced “kye”)-squared test.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.06 - Calculating Standard Deviation

Example 2.03-1 Calculate the mean and sample standard deviation for the following data set:

193, 188, 202, 185, 179, 217, 191 199, 201, 214,

193, 232, 199, 210, 196, 211, 191, 203, 201, 195

$$\sigma = \sqrt{\frac{\sum(x_i - \bar{x})^2}{(n-1)}}$$

2.03.07 - Purpose of a Chi-Squared Test

The Chi-squared test is used to determine the precision of a counting system.

Precision is a measure of exactly how a result is determined without regard to its accuracy.

It is a measure of the reproducibility of a result or, in other words, how often that result can be repeated or how often a "success" can be obtained.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.07 - Purpose of a Chi-Squared Test

This test results in a numerical value, called the Chi-squared value (X^2), which is then compared with a range of values for a specified number of observations or trials.

This range represents the 2 expected (or predicted) probability for the chosen distribution.

If the X^2 value is lower than the expected range, this tells us that there is not a sufficient degree of randomness in the observed data. If the value is too high, it tells us that there is too much randomness in the observed data.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.07 - Purpose of a Chi-Squared Test

The Chi-squared test is often referred to as a "goodness-of-fit" test.

If it does NOT fit a curve indicating sufficient randomness, then the counting instrument may be malfunctioning.

$$X^2 = \frac{\sum(x_i - \bar{x})^2}{\bar{x}}$$

2.03.07 - Purpose of a Chi-Squared Test

Calculating the Chi-Squared Value

- Using the data from Example 2.03-1 (See 2.03.06, Calculating Standard Deviation), determine the Chi-squared value for the data set.
- If we assume a given set of data passes the Chi-squared test, the data then can be used to prepare quality control charts for use in verifying the consistent performance of the counting system.

2.03.08 - Criteria for Acceptable Chi-squared Values

Most RCTs at LANL will not be expected to perform Chi-squared tests. When an RCT is tasked with performing Chi-squared tests, he or she receives facility-specific training or mentoring.

2.03.09 - Quality Control (QC) Charts

QC charts may be prepared using source counting data obtained during system calibration.

Because this test verifies that the equipment is still operating within an expected range of response, we clearly cannot change the conditions of the test in mid-stream.

QC charts, then, enable us to track the performance of the system while in use.

2.03.09 - Quality Control (QC) Charts

Data that can be used for quality control charts include gross counts, counts per unit time, and efficiency.

Most nuclear laboratories use a set counting time corresponding to the normal counting time for the sample geometry being tested.

When the system is calibrated and the initial calculations are performed, the numerical values of the mean ± 1, 2, and 3 standard deviations are also determined.

2.03.09 - Quality Control (QC) Charts

Using graph paper or a computer graphing software, lines are drawn all the way across the paper at those points corresponding to the mean; the mean plus 1, 2, and 3 standard deviations; and the mean minus 1, 2, and 3 standard deviations.

The daily control check results are then plotted on the control chart to see if the results fall outside the limits.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.10 – Maintenance and Review of QC Charts

Most RCTs at LANL will not be expected to maintain or review QC charts. When an RCT is tasked with maintaining and reviewing QC charts, he or she receives facility-specific training or mentoring.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.11 - Calculating Warning and Control Limits

System Operating Limits

- The values corresponding to ±2 and ±3 standard deviations may be called the upper and lower warning and control limits, respectively (or other terms such as action limits).
- The results of the daily source counts are graphed in many count rooms.
- Most of the time results will lie between the lines corresponding to ±1 standard deviation (68.2%).

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.11 - Calculating Warning and Control Limits

System Operating Limits

- We also know that 95.4% of the time our count will be within ±2 standard deviations and that 99.97% of the time our count will be within ±3 standard deviations.
- Counts that fall outside the warning limit (±2 σ) are not necessarily incorrect.
- Statistical distribution models say that we should get some counts in that area.
- Counts outside the warning limits indicate that something MAY be wrong.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.11 - Calculating Warning and Control Limits

System Operating Limits

- The same models say that we will also get some counts outside the control limits (±3 σ).
- However, not very many measurements will be outside those limits.
- We use 3 σ as the control – a standard for acceptable performance. In doing so we say that values outside of ±3 σ indicate unacceptable performance, even though those values may be statistically valid.

2.03.11 - Calculating Warning and Control Limits

System Operating Limits

- True randomness also requires that there be no patterns in the data that are obtained; some will be higher than the mean, some will be lower, and some will be right on the mean.
- When patterns do show up in quality control charts, they are usually indicators of systematic error. For example:
  - Multiple points outside 2 sigma
  - Repetitive points (n out of n) outside 1 sigma
  - Multiple points, in a row, on the same side of the mean
  - Multiple points, in a row, going up or down.

2.03.11 - Calculating Warning and Control Limits

System Operating Limits

- The assumption is made that systematic error is present in our measurements, and that our statistical analysis has some potential for identifying its presence.
- However, industry assumption is that systematic error that is present is very small in comparison with random error.
- Quality control charts should be maintained in the area of the radioactivity counting system so that they will be readily accessible to those who operate the system.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.11 - Calculating Warning and Control Limits

System Operating Limits

- These charts can then be used by operators to determine if routine, periodic checks (typically daily) have been completed before system use.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.12 - Determining Efficiencies and Correction Factors

Counter Efficiency

- A detector intercepts and registers only a fraction of the total number of radiations emitted by a radioactive source.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.12 - Determining Efficiencies and Correction Factors

Counter Efficiency *(continued)*

- The major factors determining the fraction of radiations emitted by a source that are detected include the fraction:
  - of radiations emitted by the source that travel in the direction of the detector window
  - emitted in the direction of the detector window that actually reach the window
  - of radiations incident on the window that actually pass through the window and produce an interaction
  - scattered into the detector window

2.03.12 - Determining Efficiencies and Correction Factors

Counter Efficiency *(continued)*

- In principle, all radiation detectors will produce an output pulse for each particle or photon that interacts within its active volume.
- Because of the factors outlined above, only a fraction of the disintegrations occurring in a source result in counts being reported by the detector.
- Therefore, only a certain fraction of the disintegrations occurring results in counts reported by the detector.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.12 - Determining Efficiencies and Correction Factors

Counter Efficiency *(continued)*

- Using a calibrated source with a known activity, a precise figure can be determined for this fraction.
- This value can then be used as a ratio to relate the number of pulses counted to the number of particles and/or photons emitted by the source.
- This ratio is called the efficiency.
- The detector efficiency gives us the fraction of counts per disintegration, or c/d.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.12 - Determining Efficiencies and Correction Factors

Counter Efficiency *(continued)*

- Since activity is the number of disintegrations per unit time, and the number of counts are detected in a finite time, the two rates can be used to determine the efficiency if both rates are in the same units of time.
- Counts per minute (cpm) and disintegrations per minute (dpm) are the most common.

2.03.13 - Calculate Efficiencies and Correction Factors

Thus, the efficiency, E, can be determined as shown in Equation (6).

$$E = \frac{cpm}{dpm} = \frac{c}{d}$$

Used in this manner the time units will cancel, resulting in c/d.

The efficiency obtained in the formula above will be in fractional or decimal form. To calculate the percent efficiency, the fraction can be multiplied by 100. For example, an efficiency of 0.25 would mean 0.25 × 100, or 25%.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.13 - Calculate Efficiencies and Correction Factors

Calculate Efficiency

- Example 2.03-3: A source is counted and yields 2840 cpm. If the source activity is known to be 12,500 dpm, calculate the efficiency and percent efficiency.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.13 - Calculate Efficiencies and Correction Factors

Calculating Activity

- By algebraic manipulation, Equation (6) can be solved for the disintegration rate [see Equation (7)].
- The system efficiency is determined as part of the calibration.
- When analyzing samples, a count rate is reported by the counting system.
- Using Equation 7, the activity, (A), of the sample can be determined in dpm, and then converted to any other units of activity (e.g., Ci or Bq).

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.13 - Calculate Efficiencies and Correction Factors

Calculating Activity *(continued)*

Equation (7)

$$dpm = \frac{cpm}{E} \rightarrow A_{dpm} = \frac{cpm}{E}$$

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.13 - Calculate Efficiencies and Correction Factors

Calculating Activity *(continued)*

- Example 2.03-4: A sample is counted on a system with a 30% efficiency. If the detector reports 4325 net cpm, what is the activity of the sample in dpm?

2.03.13 - Calculate Efficiencies and Correction Factors

Calculating Correction Factors

- A correction factor (CF), which is simply the inverse of the efficiency, is used by multiplying it by the net count rate to determine the activity, as in Equation (8).

$$CF = \frac{1}{E}$$

2.03.13 - Calculate Efficiencies and Correction Factors

Calculating Correction Factors *(continued)*

- Example 2.03-5: An instrument has an efficiency of 18%. What is the correction factor?
- *Note: This count-rate correction factor should not be confused with a geometry correction factor used with some radiation instruments, such as the beta correction factor for a Cutie Pie (RO-3C).*

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.14 - Meaning of Counting Data Reported as x ± y

The error present in a measurement governed by a statistical model can be calculated using known parameters of that model.

Nuclear laboratories are expected to operate at a high degree of precision and accuracy.

However, because we know that our measurements contain some error, we are tasked with reporting measurements to outside agencies in a format that identifies that potential error.

2.03.14 - Meaning of Counting Data Reported as x ± y

Error Calculations

- The format that is used should specify the activity units and a range in which the number must fall.
- In other words, the results would be reported as a given activity plus or minus the error in the measurement.
- Because nuclear laboratories prefer to be right more than they are wrong, counting results are usually reported in a range that would be correct 95% of the time, or at a 95% confidence level (CL).

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.14 - Meaning of Counting Data Reported as x ± y

Error Calculations *(continued)*

- To do this, the reported result should be in the format of Equation (9).

$$x.xx \ \pm yy(K_{\sigma})$$

- Where
  - x.xx = the measured activity, in units of dpm, Ci, or Bq
  - yy = the associated potential (or possible) error in the measurement
  - K = the multiple of counting error
  - σ = the standard deviation at a stated CL

2.03.14 - Meaning of Counting Data Reported as x ± y

Error Calculations *(continued)*

- Note: The use of K σ is required only for CLs other than 68% (see Table 4). Therefore:
  - σ = 1× σ 68% CL (optional)
  - 1.64 σ = 1.64 × σ 90% CL (sometimes used)
  - 2 σ = 1.96 × σ 95% CL (normally used)
- For example, a measurement of 150 ± 34 dpm (2 σ) indicates the activity as 150 dpm; however, it could be as little as 116 dpm or as much as 184 dpm with 95% confidence (at 2 σ).

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.15 - Results to Desired Confidence Level

The calculations of the actual range of error are based on the standard deviation for the distribution.

In the normal (or Gaussian) distribution, the standard deviation of a single count is defined as the square root of the mean, or $\sigma = \sqrt{\bar{x}}$.

The error, e, present in a single count is some multiplier, K, multiplied by the square root of that mean (i.e., some multiple times the standard deviation, K σ).

The value of K used is based on the CL that is desired, and is derived from the area of the curve included at that CL (see Figure 5).

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.15 - Results to Desired Confidence Level

Table 4. Counting Error Multiples

Error	Confidence Level (%)	K
Probable	50	0.6745
Standard	68	1.0000
9/10	90	1.6449
95/100	95	1.9600
99/100	99	2.5750

2.03.15 - Results to Desired Confidence Level

To calculate the range to the point at which you would expect to be right 95% of the time, you would multiply the standard deviation by 1.96, and report the results of the measurement as x.xx dpm ± yy dpm (2 σ).

Note that using a 68% or 50% CL introduces an expected error a large percentage of the time.

Therefore, for reasonable accuracy a higher CL must be used.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.15 - Results to Desired Confidence Level

The simple standard deviation (σ) of the single count (x) is usually determined as a count rate (counts per unit time) by dividing the count rate (R) by the count time (T).

Subscripts can be applied to distinguish sample count rates from background count rates.

Equation (10)

$$\sigma = K\sqrt{\frac{R}{T}}$$

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.15 - Results to Desired Confidence Level

Example 2.03-6: The count rate for a sample was 250 cpm. Assume a 10-minute counting time, zero background counts and a 25% efficiency. Report the sample activity at a 95% CL.

2.03.16 – Purpose of Determining Background

Radioactivity measurements cannot be made without considering the background.

Background, or background radiation, is the radiation that enters the detector concurrently with the radiation emitted from the sample being analyzed.

This radiation can be from natural sources, either external to the detector (i.e., cosmic or terrestrial) or can originate inside the detector chamber that is not part of the sample.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.16 – Purpose of Determining Background

In practice, the total counts are recorded by the counter. This total includes the counts contributed by both the sample and the background.

Therefore, the contribution of the background will produce an error in radioactivity measurements unless the background count rate is determined by a separate operation and subtracted from the total activity, or gross count rate.

The difference between the gross and the background rates is called the net count rate (sometimes given in units of corrected counts per minute, or ccpm).

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.16 – Purpose of Determining Background

This relationship is seen in Equation (11):

$$R_S = R_{S+B} - R_B$$

Where

R_S = the net sample count rate (in cpm)

R_{S+B} = the gross sample count rate (in cpm)

R_B = the background count rate (in cpm)

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.16 – Purpose of Determining Background

The background is determined as part of the system calibration by counting a background (empty) sample holder for a given time.

The background count rate is determined in the same way as any count rate, where the gross counts are divided by the count time, as seen in Equation (12).

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.16 – Purpose of Determining Background

Equation (12)

$$R_B = \frac{N_B}{T_B}$$

Where

R_B = the background count rate (counts per time, i.e., cpm)

N_B = the gross counts, background

T_B = the background count time

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.16 – Purpose of Determining Background

In practice, background values should be kept as low as possible.

As a guideline, background on automatic counting systems should not be allowed to exceed 0.5 cpm alpha and 1 cpm beta-gamma.

If the system background is above this limit the detector should be cleaned or replaced.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.16 – Purpose of Determining Background

Reducing Background

- Typically, the lower the system background, the more reliable the analysis of the samples will be.
- In low-background counting systems the detector housing is surrounded by lead shielding to reduce the background.
- Nonetheless, some background still manages to reach the detector.

2.03.16 – Purpose of Determining Background

Reducing Background *(continued)*

- Clearly, little can be done to reduce the actual source of background due to natural sources.
- On many systems a second detector is incorporated to detect penetrating background radiation.
- When a sample is analyzed the counts detected by this second detector during the same time period are internally subtracted from the gross counts for the sample.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.16 – Purpose of Determining Background

Reducing Background *(continued)*

- Background originating inside the detector chamber can be, for the most part, more easily controlled.
- The main contributors of this type of background are:
  - Radiation emitted from detector materials
  - Radioactive material found on inside detector surfaces
  - Radioactive material found on the sample slide assembly
  - Contamination found in or on the sample planchet or planchet carrier

2.03.16 – Purpose of Determining Background

Reducing Background *(continued)*

- Unfortunately, trace levels of radioactivity exist in the materials of which detectors and their housings are made: simply a fact of life in the atomic age.
- The contribution to background from such materials is negligible, but should nonetheless be acknowledged.
- Radioactive material can be transferred from contaminated samples to the inside surfaces of the detector chamber during counting.
- This transfer usually occurs when samples having gross amounts of material on them are counted in a low-background system.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.16 – Purpose of Determining Background

Reducing Background *(continued)*

- During the insertion and withdrawal of the sample into the detector chamber, loose material can be spread into the chamber.
- To prevent this spread, these samples should be counted using a field survey instrument or a mini-scaler. Low-background systems are designed for counting lower-activity samples.
- Counting a high-activity sample on these systems should be avoided unless the sample is a sealed radioactive source.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.17 - Method and Requirements for Determining Background

Methods and requirements for determining background are specified in RCT operational procedures.

2.03.18 - Purpose of Performing Sample Planchet Maintenance

Planchets and carriers should be inspected, cleaned, and counted on a routine basis.

All in-use planchets and carriers must read less the than established site limits.

Planchets exceeding these limits should be decontaminated and recounted as necessary.

By keeping planchets as clean and free from contamination as possible, sample result reliability will be increased because the amount of error introduced in the sample analysis will be reduced.

2.03.19 - Planchet Maintenance for Counting Systems

The methods and requirements for performing planchet maintenance for counting systems are specified in RCT operational procedures.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.19 - Planchet Maintenance for Counting Systems

Propagation of Error

- The error present in a measurement includes the error present in the sample count and the error present in the background count.
- The total error in the measurement is calculated by squaring the error in the background, adding that to the square of the error in the sample count, and taking the square root of the sum, as shown in Equation (13).

2.03.19 - Planchet Maintenance for Counting Systems

Propagation of Error *(continued)*

- Equation (13)

$$e_S = \sqrt{e_{S+B}^2 + e_B^2}$$

where: e_S = error present in the measurement (sample)

e_{S+B} = error in sample count (sample plus background)

e_B = error present in background count

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.19 - Planchet Maintenance for Counting Systems

Propagation of Error *(continued)*

- Equation (14)

$$K\sigma_S = K\sqrt{\frac{R_{S+B}}{T_S} + \frac{R_B}{T_B}}$$

- Where
  - RS+B = the gross sample count rate (sample plus background)
  - RB = the background count rate
  - TS = the sample count time
  - TB = the background count time
  - K = the CL multiple (see Table 4)

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.19 - Planchet Maintenance for Counting Systems

Propagation of Error *(continued)*

- The error in the sample count is the standard deviation of the count, which is the square root of that count [see Equation (13) above].
- Example 2.03-7: An air sample is counted and yields 3500 counts for a 2-minute count period. The system background is 10 cpm, as determined over a 50-minute count time. Determine the error in the sample and report the net count rate to a 95% CL.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.19 - Planchet Maintenance for Counting Systems

Propagation of Error *(continued)*

- If the sample counting time and the background counting time are the same, the formula can be simplified even more to Equation (15).

$$K\sigma_S = K\sqrt{\frac{R_{S+B} + R_B}{T}}$$

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.19 - Planchet Maintenance for Counting Systems

Propagation of Error *(continued)*

- Example 2.03-8: A long-lived sample is counted for 1 minute and gives a total of 562 counts. A 1-minute background gives 62 counts. Report the net sample count rate to a 95% CL.

2.03.20 - Methods to Improve Statistical Validity of Sample Measurements

Minimizing the statistical error present in a single sample count is limited to several options.

If we look at the factors present in the calculation below [as in Equation (14)], we can see that there are varying degrees of control over these factors.

The standard deviation in terms of count rate:

$$\sigma_{rate} = \sqrt{\frac{R_{S+B}}{T_S} + \frac{R_B}{T_B}}$$

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.20 - Methods to Improve Statistical Validity of Sample Measurements

R_{S+B} is the sample count rate.

- **We really have no control over this**.

R_B is the background count rate.

- **We do have some control over this**.
- On any counting equipment the background should be maintained as low as possible.
- However, in most of our counting applications, the relative magnitude of the background count rate should be extremely small in comparison with the sample count rate if proper procedures are followed.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.20 - Methods to Improve Statistical Validity of Sample Measurements

R_B *(continued)*

- Size truly becomes an issue when we are counting samples for free release or environmental samples.
- However, **some reduction in error can be obtained by increasing the background counting time**, as discussed below.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.20 - Methods to Improve Statistical Validity of Sample Measurements

T_B and T_S are the background and sample count times.

- **These are the factors that we have absolute control over**.
- In the previous section, we discussed the reliability of the count itself.
- We have been able to state that a count under given circumstances may be reproduced with a certain CL, and that the larger the number of counts the greater the reliability.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.20 - Methods to Improve Statistical Validity of Sample Measurements

T_B and T_S (*continued)*

- The condition we have been assuming is that our count is taken within a given time.
- To get more precise results, many counts must be observed.
- Therefore, if we have low count rates, the counting time must be increased to obtain many counts, thereby making the result more precise (or reproducible).

2.03.20 - Methods to Improve Statistical Validity of Sample Measurements

Count times

- The total counting time required depends on both the sample and background count rates.
- For high sample activities, the sample count time can be relatively short compared with the background count time.
- For medium count rates, we must increase the sample count time to increase precision.
- As the sample activity gets even lower, we approach the case where we must devote equal time to the background and source counts.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.20 - Methods to Improve Statistical Validity of Sample Measurements

Count times (*continued)*

- In other words, by counting low activity samples for the same amount of time as that of the background, we increase the precision of our sample result.
- However, we must never count a sample for a period of time longer than the system background.

To summarize this section, by minimizing the potential error present, we improve the statistical validity of our measurements.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.21 - Detection Limits

The *detection limit* of a measurement system refers to the statistically determined quantity of radioactive material (or radiation) that can be measured (or detected) at a preselected CL.

This limit is a factor of both the instrumentation and the technique/procedure being used.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.21 - Detection Limits

The two parameters of interest for a detector system with a background response greater than zero are L_C and L_D (Figure 6).

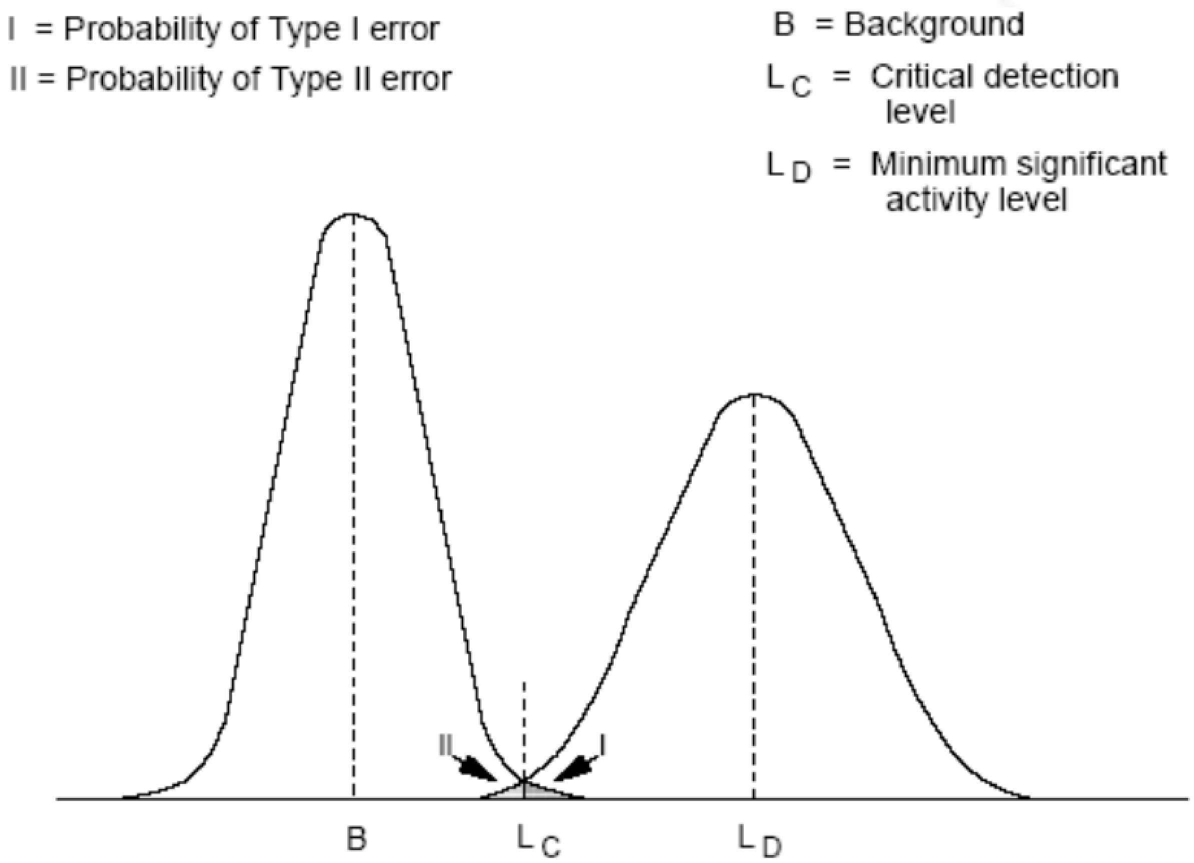
- **LC – Critical detection level**: the response level at which the detector output can be considered "above background"
- **LD – Minimum significant activity level**: the activity level that can be seen with a detector with a fixed level of certainty

The detection levels can be calculated by the use of Poisson statistics, assuming that random errors and systematic errors are separately accounted for and that there is a background response.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.21 - Detection Limits

Figure 6. Errors in Detection Sensitivity



2.03.21 - Detection Limits

For these calculations, two types of statistical counting errors must be considered quantitatively to define acceptable probabilities for each type of error:

- **Type I** – occurs when a detector response is considered above background when in fact it is not (associated with LC)
- **Type II** – occurs when a detector response is considered to be background when in fact it is greater than background (associated with LD)

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.21 - Detection Limits

If the two probabilities (areas labeled I and II in Figure 6) are assumed to be equal, and the background of the counting system is not well-known, then the LC and the LD can be calculated.

The two values would be derived using the equations LC = $k\sigma_B$ and LD = $k^2 + 2k\sigma_B$, respectively.

If 5% false positives (Type I error) and 5% false negatives (Type II error) are selected to be acceptable levels, i.e., a 95% CL, then k = 1.645 and the two equations can be written as Equations (16) and (17).

2.03.21 - Detection Limits

Equation (16)

$$L_C = 1.645\sqrt{\frac{R_B}{T_B} + \frac{R_B}{T_B}}$$

Equation (17)

$$L_D = \frac{3}{T_S} + 3.29\sqrt{\frac{R_B}{T_B} + \frac{R_B}{T_B}}$$

2.03.21 - Detection Limits

Equations (16) and (17) continued

Where

- L_C = the critical detection level
- L_D = the a priori (before the fact) detection limit (minimum significant activity level)
- R_B = the background count rate
- T_B = the background count time
- T_S = the sample count time

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.21 - Detection Limits

The minimum significant activity level, L_D, is the a *priori* activity level that an instrument can be expected to detect 95% of the time.

In other words, it is the smallest amount of activity that can be detected at a 95% CL.

When stating the detection capability of an instrument, this value should be used.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.21 - Detection Limits

The critical detection level, L_C, is the lower bound on the 95% detection interval defined for L_D, and is the level at which there is a 5% chance of calling a background value “greater than background.”

This value (L_C) should be used when actually counting samples or making direct radiation measurements.

Any response above this level should be counted as positive and reported as valid data. This action will ensure 95% detection capability for L_D.

2.03.21 - Detection Limits

If the sample count time (TS) is the same as the background count time (TB), then equations (16) and (17) can be simplified as follows:

- Equation (18) $$L_C = \sqrt{\frac{R_B}{T}}$$
- Equation (19) $$L_D = \frac{3}{T} + \sqrt{\frac{R_B}{T}}$$
- Where T = the count time for sample and background

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.21 - Detection Limits

Therefore, the full equations for L_C and L_D must be used when the count times for the samples and background are different (when 95% CL is used).

These equations assume that the standard deviation of the sample planchet/carrier background during the sample count (where the planchet/carrier is assumed to be 0 activity) is equal to the standard deviation of the system background (determined using the background planchet/carrier).

2.03.21 - Detection Limits

The critical detection level, L_C, is used when reporting survey results; at a 95% CL, samples above this value are radioactive.

This calculation then presupposes that 5% of the time, clean samples will be considered radioactive.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.21 Detection Limits

The minimum significant activity level, L_D, also referred to as the lower limit of detection (LLD) in some texts, is calculated before samples are counted.

This value is used to determine minimum count times based on release limits and airborne radioactivity levels. In using this value we are saying that at a 95% CL, samples counted for at least the minimum count time calculated using the LD that are positive will indeed be radioactive (above the LC).

This calculation then presupposes that 5% of the time samples considered clean will actually be radioactive.

2.03.21 - Detection Limits

Example 2.03-9

- A background planchet is counted for 50 minutes and yields 16 counts. Calculate the critical detection level and the minimum significant activity level for a 0.5 minute sample count time.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.21 - Detection Limits

Minimum Detectable Activity (MDA)

- The minimum significant activity level, L_D , can be used to evaluate whether the measurement process is adequate to meet requirements.
- For example, the results of Example 2.03-9 (in units of cpm) can be converted using counting efficiency and the area of the swipe to determine the adequacy of the measurement system for contamination surveys for removable contamination performed to ensure that the removable surface contamination values specified in Appendix D of 10 CFR 835 are not exceeded (in units of $dpm/100cm^2$).

2.03.21 - Detection Limits

Minimum Detectable Activity (MDA) *(continued)*

- In most cases, swipes to determine the removable contamination levels will be counted in the field or submitted to the counting lab for analysis, where the background radiation levels are sufficiently low enough to ensure that L_D, and thus the MDA, are below the limits in 10 CFR 835 Appendix D.

2.03.21 - Detection Limits

Minimum Detectable Activity (MDA) *(continued)*

- Equation (20)

$$MDA_{removable} = L_D \times \frac{100/A_{swipe}}{e}$$

- Where
  - $MDA_{removable}$ = the activity level in dpm/100 cm^2
  - e = the detector efficiency in counts per disintegration
  - A_{swipe} = the area of the surface swiped in cm^2

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.21 - Detection Limits

Minimum Detectable Activity (MDA) *(continued)* –
Static Count MDAs

- Similarly, an MDA can be calculated for a static field measurement to evaluate total surface contamination values.
- In this case, an adjustment is needed to account for the size of the detector.
- To determine the MDA for static counts, the probe is stationary for a prescribed period of time, and Equation (19c) is used.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.21 - Detection Limits

Minimum Detectable Activity (MDA) *(continued)* –
Static Count MDAs *(continued)*

- Equation (21)

$$MDA_{total} = L_D \times \frac{100/A_{swipe}}{e}$$

- Where
  - MDA_{total} = the activity level in dpm/100 cm^2
  - e = the detector efficiency in counts per disintegration
  - A_{probe} = the surface area of the probe in cm^2

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.21 - Detection Limits

Minimum Detectable Activity (MDA) *(continued)* – Scanning MDAs

- The ability to identify a small region or area of slightly elevated radiation during surface scanning is dependent on the RCT's skill in recognizing an increase in the audible output of the instrument.
- Experience has shown that a 25% to 50% increase may be easily identifiable at ambient background levels of several thousand counts per minute, whereas, at ambient levels of a few counts per minute, a two- to three-fold increase in the audible signal is required before a change is readily recognizable.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.21 - Detection Limits

Minimum Detectable Activity (MDA) *(continued)* – Scanning MDA *(continued)*

- The detection sensitivity of scanning is dependent on many other factors, such as detector scan speed, surface characteristics, size of elevated activity region, surveyor efficiency, level of activity, and detector/surface distance.

- The ability to detect an elevated region of activity using a particular survey scanning technique would need to be determined empirically and is beyond the scope of this training.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.22 - Calculate Detection Limit Values for Counting Systems

LANL uses the following standard MDA formula:

$$MDA = \frac{2.71 + 3.29\sqrt{R_B T_S \left(1 + \frac{T_S}{T_B}\right)}}{Eff \times T_S}$$

Where

- R_B = the background count rate in cpm
- T_S = the sample count time in seconds
- T_B = the background count time in seconds
- Eff = the detector efficiency

Important! If an instrument reads in dpm, R_B must be converted to cpm before plugging into this formula.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.23 - Determining Crosstalk

Discrimination

- Crosstalk is a phenomenon that occurs on proportional counting systems (such as a Tennelec) that use electronic, pulse-height discrimination, thereby allowing the simultaneous analysis for alpha and beta-gamma activity.
- Discrimination is accomplished by establishing two thresholds, or windows, which can be set in accordance with the radiation energies of the nuclides of concern.
- Recall that the pulses generated by alpha radiation will be much larger than those generated by beta or gamma.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.23 - Determining Crosstalk

Discrimination *(continued)*

- This difference in pulse height makes the discrimination between alpha and beta-gamma possible.
- Beta and gamma events are difficult to distinguish; thus, they are considered as one by such counting systems.

2.03.23 - Determining Crosstalk

Discrimination *(continued)*

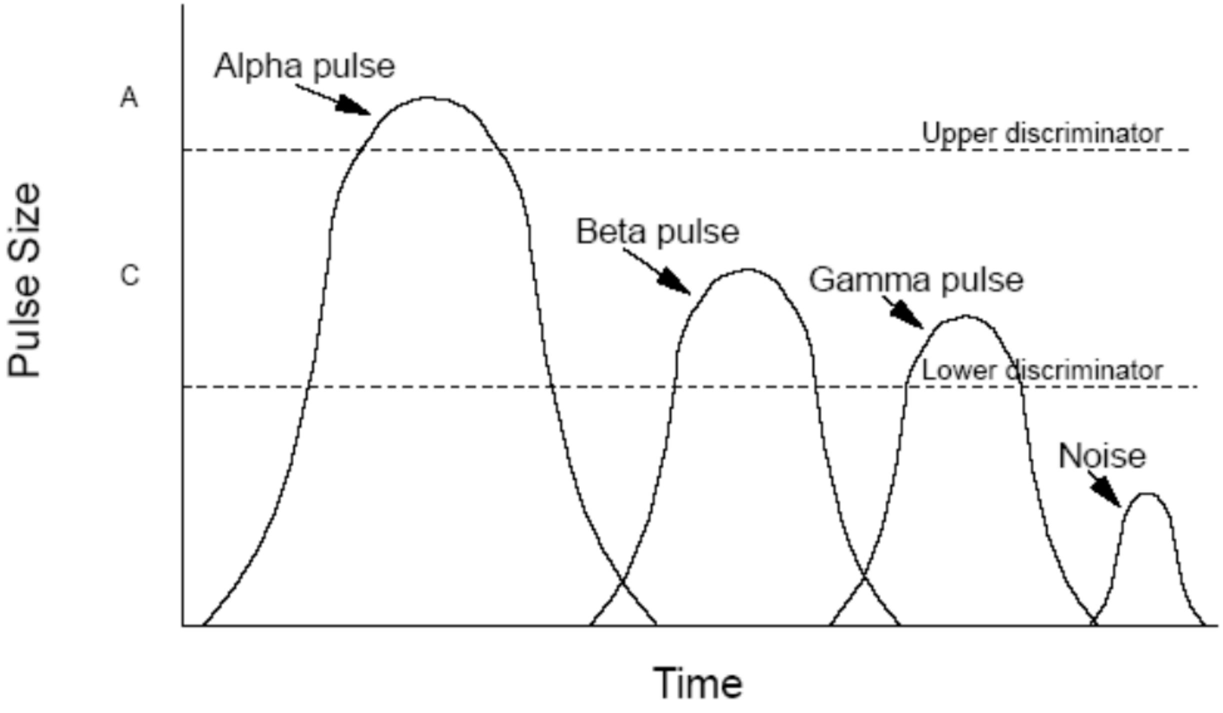
- In practice, the lower window is set such that electronic noise and ultra-low-energy photon events are filtered out.
- Any pulse generated that has a size greater than the setting for the lower window is considered an event, or a count.
- The upper window is then set such that any pulses that surpass the upper discriminator setting will be considered an alpha count (see Figure 7).

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.23 - Determining Crosstalk

Discrimination *(continued)*

Figure 7. Pulse-height Discrimination



* C - A = B

2.03.23 - Determining Crosstalk

Discrimination *(continued)*

- For output purposes, the system routes each count to a series of channels which simply keep a total of the counts routed to them.
- Channel A is for alpha counts, Channel B is for beta-gamma counts, and Channel C is for total counts.
- As a sample is being counted, all valid counts registered (i.e., those which surpass the lower discriminator setting) are routed to the C channel.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.23 - Determining Crosstalk

Discrimination *(continued)*

- In addition, if the count was considered an alpha count (i.e., it surpassed the upper discriminator setting) it is routed to the A channel; otherwise, it is tallied in the B channel.
- In effect, the number of beta-gamma counts (Channel B) are determined by subtracting the number of alpha counts (Channel A) from the total counts (Channel C), or B = C - A.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.23 - Determining Crosstalk

Origin of Crosstalk

- Now that we understand the process involved, a dilemma stems from the fact that events are identified by the system as either alpha or beta-gamma according to the size of the pulse generated inside the detector.
- The system cannot really tell what type of radiation has generated the pulse.
- Rather, the pulse is labeled as “alpha” or “beta-gamma” by comparing the size of the pulse with the discriminator setting.
- The setting of the discriminator poses the dilemma.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.23 - Determining Crosstalk

Origin of Crosstalk *(continued)*

- Alpha particles entering the detector chamber generally are attenuated by the detector fill gas because of their high LET, thereby producing a large pulse.
- Low-energy beta particles and photons will also lose all their energy within the detector gas, but nevertheless produce a smaller pulse because of their lower energies.
- High-energy beta particles can still retain some of their energy even after having produced a pulse while traversing the detector volume.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.23 - Determining Crosstalk

Origin of Crosstalk *(continued)*

- Rather than leaving the detector, as would a photon, the beta is reflected off of the detector wall and reenters the volume of gas, causing ionizations and generating a second pulse.
- These two pulses can be so close together that the detector sees them as one large pulse.
- Because of the large pulse size, it can surpass the upper discriminator setting and is therefore counted as an alpha and not as a beta.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.23 - Determining Crosstalk

Origin of Crosstalk *(continued)*

- The result is that alpha activity can be reported for a sample when in fact little or no alpha was present.
- Conversely, if a true alpha-generated pulse is not large enough to exceed the upper discriminator, it would be counted as a beta-gamma event.
- This is *crosstalk*.

2.03.23 - Determining Crosstalk

Origin of Crosstalk *(continued)*

- The solution is not simple. The setting of the upper discriminator depends on the radiations and energies of the sources and samples being analyzed.
- If high-energy beta radiations are involved, a significant portion of them could be counted as alpha events if the setting is too low.
- If the setting is too high, lower-energy alpha events could be counted as beta-gamma.
- Typically, the setting of the discriminator will usually be some “happy medium.” A discussion of how this can be dealt with follows.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.23 - Determining Crosstalk

Calibration Sources and Crosstalk

- For calibrations of Tennelec counting systems, the manufacturer provides the following general recommendations for discriminator settings:
  1. Using an Sr-90 beta source, set the upper (A) discriminator such that there is 1% beta-to-alpha crosstalk.
  2. Using a Po-210 alpha source, set the A+B discriminator such that there is less than 3% alpha-to-beta crosstalk.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.23 - Determining Crosstalk

Calibration Sources and Crosstalk *(continued)*

- Energies of sources used to calibrate counting systems should be the same as, or as close as possible to, the energies of radionuclides in the samples analyzed.
- Wherever possible they should be a pure emitter of the radiation of concern.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.23 - Determining Crosstalk

Calibration Sources and Crosstalk: Sr-90

- For beta-gamma sources, the most popular isotope in radiation protection is Sr-90.
- This isotope has a relatively long half-life of 29.1 years, but emits betas of only 546 keV.
- However, Sr-90 decays to yttrium (Y)-90, another beta emitter that has a short half-life of only 2.67 days and emits a 2.281-MeV beta.
- Y-90 decays to zirconium (Zr)-90m, which emits a 2.186-MeV gamma almost instantaneously to become stable.

2.03.23 - Determining Crosstalk

Calibration Sources and Crosstalk: Sr-90 *(continued)*

- The daughters reach equilibrium with the strontium parent within a number of hours after source assay.
- Therefore, for every Sr beta emitted a Y beta is also emitted, thereby doubling the activity.
- These sources are often listed as Sr/Y-90 for evident reasons.
- This makes Sr/Y-90 sources an excellent choice, and they are used by many sites for calibrations and performance testing.

2.03.23 - Determining Crosstalk

Calibration Sources and Crosstalk: Po-210

- Polonium-210 is essentially a pure alpha emitter, which is primarily why it is recommended for calibrations and performance testing.
- This isotope yields a strong alpha, but it also has a short half-life.
- A comparison of some alpha emitters is given in Table 5.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.23 - Determining Crosstalk

Calibration Sources and Crosstalk: Po-210 *(continued)*

Table 5. Alpha Emitters

Isotope	Half-Life	Energy (MeV)
Po-210	138.38 days	5.3044
Pu-239	2.4×10^4 years	5.156, 5.143, 5.105
Ra-226	1.60×10^3 years	4.78, 4.602
Th-230	7.54×10^4 years	4.688, 4.621
Natural U	4.4×10^9 years (avg.)	4.2 (avg.)

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.24 - Acceptable Values of Crosstalk for Counting Systems

The alpha-to-beta crosstalk must be less than 50%.

The beta-to-alpha crosstalk must be less than 10%.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.25 – Voltage Plateaus

Very simply put, a voltage plateau is a graph that indicates a detector's response to a specific energy particle with variations of high voltage.

The x axis represents the high voltage, and the y axis represents the response (i.e., counts).

The resulting curve gives an indication of detector quality, and can indicate any problems with the counting gas.

The curve can also be used to determine the optimum operating high voltage for the system.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.25 – Voltage Plateaus

Most automatic low-background counting systems provide several different analysis modes.

These modes count samples at certain pre-determined voltages.

Counting systems generally provide three analysis modes:

- ALPHA ONLY
- ALPHA THEN BETA
- ALPHA AND BETA (SIMULTANEOUS)

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.25 – Voltage Plateaus

Two voltage settings usually are used in conjunction with these analysis modes:

- Alpha voltage (lower)
- (Alpha plus) Beta voltage (higher)

Recall that in a proportional counter the amount of voltage determines the amount of gas multiplication.

2.03.25 – Voltage Plateaus

Because of the high LET of alpha radiation, at a lower voltage, even though the gas amplification will be lower, alpha pulses will still surpass the lower discriminator and some will even pass the upper discriminator.

Because of the lower gas amplification beta-gamma pulses will not be large enough to be seen.

Therefore, any counts reported for the sample will be alpha counts.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.25 – Voltage Plateaus

In the ALPHA ONLY mode, the sample is counted once, at the alpha voltage.

Counts may appear in either the A or B channels.

Upon output, the A and B channels will be added together and placed in Channel A and therefore reported as alpha counts; the B channel will be cleared to zero, thereby resulting in no beta-gamma counts.

2.03.25 – Voltage Plateaus

In the ALPHA THEN BETA mode, the sample is counted twice.

- The first count interval determines the alpha counts using the alpha voltage.
- The second count is done at the beta voltage.

The determination of alpha and beta-gamma counts in this mode is based strictly on the operating characteristics of the detector at the different voltages.

Thus, the A and B counts are summed during both counting intervals to attain the total counts.

2.03.25 – Voltage Plateaus

The separation of alpha and beta-gamma counts is then calculated and reported according to Formula (20) as

$$\alpha = \frac{A_1 + B_1}{CF_\alpha} \qquad \beta = (A_2 - B_2) - \alpha \ ,$$

where

- α = the reported gross alpha counts
- β = the reported gross beta-gamma counts
- A_1, B_1 = the accumulated channel counts respectively, first interval
- A_2,B_2 = the accumulated channel counts respectively, second interval
- CF_α = the alpha correction factor (ratio of alpha efficiency at alpha voltage to efficiency at beta voltage)

2.03.25 – Voltage Plateaus

In the ALPHA AND BETA (SIMULTANEOUS) mode, the sample is counted once using the beta voltage. Alpha events are reported in the A channel, whereas beta-gamma counts are reported in the B channel. This mode is used most often.

As can be seen, the setting of the two voltages will have a direct impact on the number of counts reported for a given sample. The determination of what these voltage settings should be must be done such that the optimum performance of the detector is obtained for those voltage regions. This determination is the purpose of a plateau.

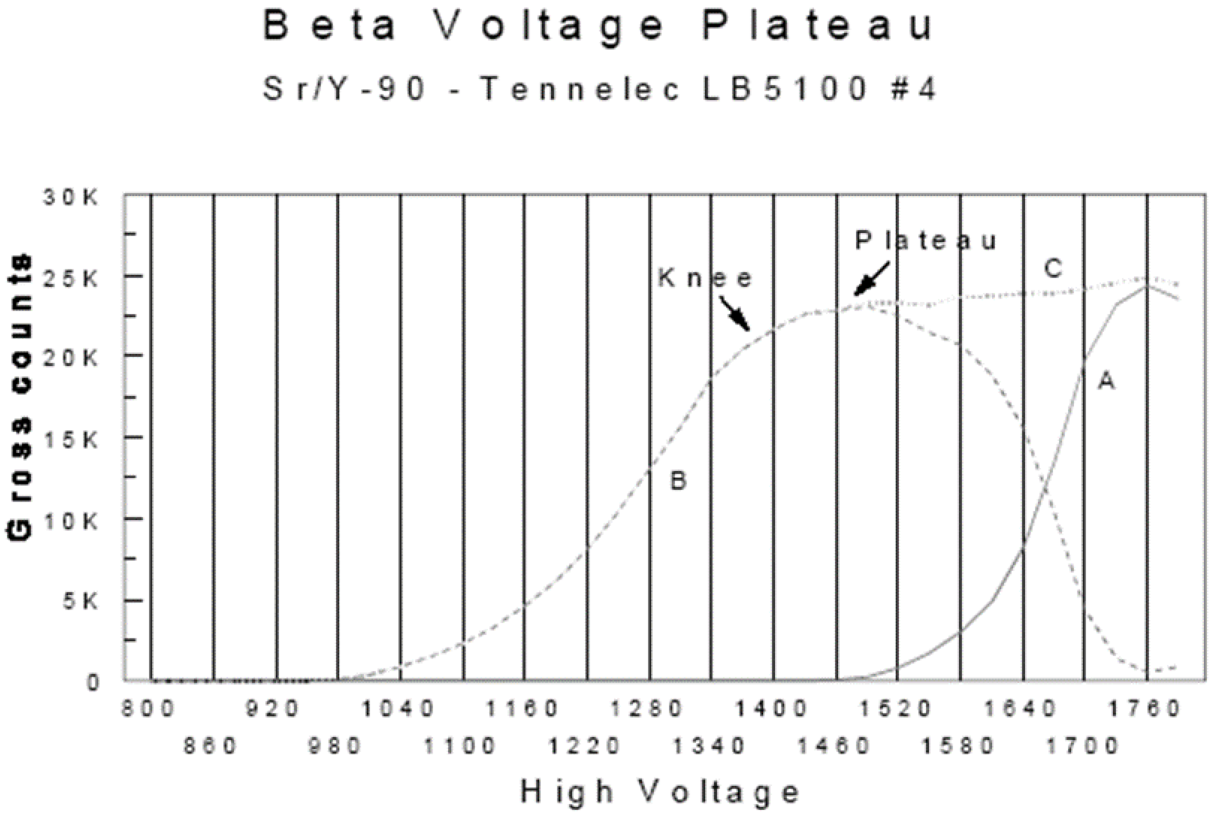
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.26 - Method of Performing a Voltage Plateau on Counting Systems

RCTs are not expected to perform voltage plateaus at LANL.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.26 - Method of Performing a Voltage Plateau on Counting Systems



Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.26 - Method of Performing a Voltage Plateau on Counting Systems

In conjunction with initial system setup and calibration by the vendor, two voltages plateaus are performed--alpha voltage and beta voltage.

For P-10 gas, the alpha plateau is started at about 400 V and the beta plateau at about 900 V.

The plateaus are developed by plotting the gross counts accumulated for each radionuclide.

2.03.26 - Method of Performing a Voltage Plateau on Counting Systems

Each time a count is completed, the high voltage is incremented a specific amount, typically 25 to 50 V, and another count is accumulated.

This process is repeated until the end of the range is reached, typically about 1800 V.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.26 - Method of Performing a Voltage Plateau on Counting Systems

With the high voltage set at the starting point, few or no counts are observed because of insufficient ion production within the detector.

As the voltage is increased, a greater number of pulses is produced with sufficient amplitude to exceed the discriminator threshold; these pulses are then accumulated in the counter.

There will be a high voltage setting where the increase in counts levels off (see Figure 8). This area is the detector plateau. Further increases in high voltage result in little change in the overall count rate.

2.03.26 - Method of performing a voltage plateau on counting systems

The plateau should remain flat for at least 200 V using an Sr/Y-90 source, which indicates the plateau length.

Between 1750 and 1850 V, the count rate will start to increase dramatically.

This is the avalanche region, and the high voltage should not be increased any further.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

2.03.26 - Method of Performing a Voltage Plateau on Counting Systems

The region where the counts level off is called the knee of the plateau.

The operating voltage is chosen by viewing the plateau curve and selecting a point 50 to 75 V above the knee and where the slope per 100 V is less than 2.5%.

This action ensures that minor changes in high voltage will have negligible effects on the sample count.

2.03.26 - Method of Performing a Voltage Plateau on Counting Systems

Poor counting gas or separation of the methane and argon in P-10 can result in a very high slope of the plateau.

Upon initial system setup and calibration the vendor determines and sets the optimum operating voltages for the system.

Thereafter, plateaus should be generated each time the counting gas is changed.