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Statistical Parameters Analysis Experiment for ^{137}Cs and ^{60}Co sources: A Review

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Abstract: *In this review, some important statistical parameters were determined to investigate how the energies of two radioactive samples are normally distributed. Statistical parameters were calculated in the present study: Variance (σ^2), Standard Deviation (σ or s), and Standard error ($\sigma_{\bar{x}}$) as well as drawn histogram and box plot. These parameters were comely used in nuclear laboratories or nuclear experiments. Most of the statistical nature of radioactivity relies on the assumption that statistical processes normally contain a standard deviation due to the inaccuracy of nuclear measurements. This comprehensive study aimed to quantify the comparison between the energies of cesium-137 and cobalt-60 isotope samples conducted using the distribution in SPSS. The review in the current study has shown that there is a clear effect of the gamma-ray energy used in these parameters under study.*

Keywords: *radioactivity, standard deviation, standard error, histogram and box plot.*

I. Introduction

Radioactivity takes place when certain sorts of isotopes release energy through the process of disintegration. Out of this method, the radioactive nuclide or even its isotope undergoes subjective decays via expelling the excess energy as radiation emission or subatomic particles [1]. The importance of radioactivity analysis is accounting for monitoring natural radioactive materials, the health of the surroundings, means of getting rid of waste, remediating sites, conforming to mining regulations, and power obstetrics [2]. Sometimes the radiation from radioactive materials is a good aid in the analysis by exposing the examined material to one of the radiation sorts [3]. Measurement involves an uncertain interaction between the observer and the object being seen. Consequently, the observed magnitudes are constantly replicated with a certain degree of error due to the equipment. Because of the uncertainty in the measurements, error theory is necessary [4]. When we measure radioactive compounds, the issue becomes much more problematic because radioactive disintegration is an unpredictable process. In radioactivity counting, there are two categories of changes: those caused by the sample's activity (when a radioactive substance has a short half-life) and those caused by the random nature of radioactivity breakdown (which changes disintegration rates over time) [5]. The concept of counting statistics must be used since the measurement of radioactivity indicates values with varying degrees of validity and reliability. Many physical measurement kinds have a given measured amount; the only variables that affect the measurement are statistical ones. But when it comes to radioactivity measurements, things are different [6]. Since specific statistics govern the radioactive decay process, the activity value of a sample is a mean value that changes over time rather than a fixed number. The frequent measurements of the radioactivity of any source are unequal. When the measuring equipment disturbance is negligent, the emission rates must govern the same statistical law, so their standard deviation rates are equal from a statistical point of view. Besides, the high-counting range makes the Gaussian statistics much closer to the Poisson statistics [7]. Radioactive nuclear products such as cobalt and cesium are major pollutants of soil and water and pose a risk to human health due to their transfer through the food chain. Cobalt and cesium are relatively high-energy gamma-ray emitters, with about 0.6614 MeV of gamma-rays from cesium-137 and two energies per disintegration of gamma-ray emissions of 1.1715 and 1.3316 MeV from cobalt-60 [8, 9]. The present review aims to determine some important statical parameters such as standard deviation, standard error, histogram, and box plot that were commonly used in measurement experiments in nuclear laboratories.

II. Experimental

The experimental setup used a gamma-ray source consisting of ^{137}Cs and ^{60}Co radioactive elements with an activity level of 0.1µCi. The radionuclides ^{137}Cs and ^{60}Co have fractional half-lives of 30.2 and 5.25 years, respectively. The gamma-ray photon detecting system included a Student Geiger-Müller (GM) Tube (SPECIFICATIONS, refer to Figure 1) equipped with a 35 mm diameter mica window (2 mg cm^{-2}) in order to achieve high photon efficiency for low-activity gamma-ray sources. The dead time period of the GM tube is around 200 µs. The studies were conducted at an operating voltage of 620 V. Ten shelf places in the GM holder enable the accommodation of samples and sources for experimental measurements. The counted data were enrolled after the interaction between the released radiation from the selected sample and the Geiger- Muller tube device, which is considered one of the gas detectors. When the efficiency of the Geiger-Muller counter is high, it accurately detects the radiation and forwards the signal to the screen. This is done by means of a counter tube filled with an inert gas such as helium, argon, or neon. Under low pressure and by ionizing the gas affected by the incident radiation, it forms excitons with sufficient energy to cause secondary ionizations and thus produce the pulse [10].

Figure 1: The Geiger Muller system

III. Theoretical Equations

The mean µ or $\bar{\mathbf{x}}$ of a set of measurements (from 1 to n) is closer to accuracy than a single one.

$$\mu \text{ or } \bar{\mathbf{x}} = \frac{\sum_{i=1}^{i=n} N_i}{n} \quad \dots \dots (1)$$

The Variance (σ^2) can be calculated using the following equation [11]:

$$\sigma^2 = \frac{\sum(x_i - \mu)^2}{N-1} \ldots\ldots (2)$$

The standard deviation s (σ) can be calculated using the following equation [11]:

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2},$$

The equation for calculating the standard error of the mean (SEM) is as follows:

$$\sigma_{\bar{X}} = \frac{\sigma}{\sqrt{N}}$$

Where, $\mathbf{x_i}$ represent a single sample value, μ (**x̄**) represent the sample mean, and **N** represents the sample size.

IV. Statistical analysis

The statistical analysis in this study was conducted using the statistics software program SPSS version 26.0 for Windows.

V. Results

Table 1 shows the completion values of statistical parameters for two energies of cesium and cobalt sources. From Table 1, the values of standard deviation and standard error for both sources are different as the energy of the selected sources differs. All values of statistical parameters in the present work of ^{137}Cs were approximately higher than that of ^{60}Co. That can give a good relation and interpretation because of the energy differences between both sources. The average energy of the ^{60}Co source is 1.25155 MeV, while for ^{17}Cs it is 0.6614 MeV [9].

Table 1. Statistical parameters of gamma-ray emissions (cesium-137 and cobalt-60)

Statistical parameters	Cesium-137	Cobalt-60
Count, N	300	300
Sum, Σx	27108	19395
Mean, μ or x̄	90.36	64.65
Variance, σ^2	259.5637	171.8075
Standard Deviation, σ or s	**16.1109**	**13.1075**
Standard error $\sigma_{\bar{x}}$	0.930	0.756

Figures 2 and 3 provide histograms of the frequency distribution for the count of 137Cs and 60Co, respectively. Given that all points of the 137Cs distribution are roughly aligned with the 45-degree reference line, it may be inferred that the distributions are normal based on Spearman Correlation. While, the distribution of ^{60}Co appears normal according to the Pearson Correlation normal.

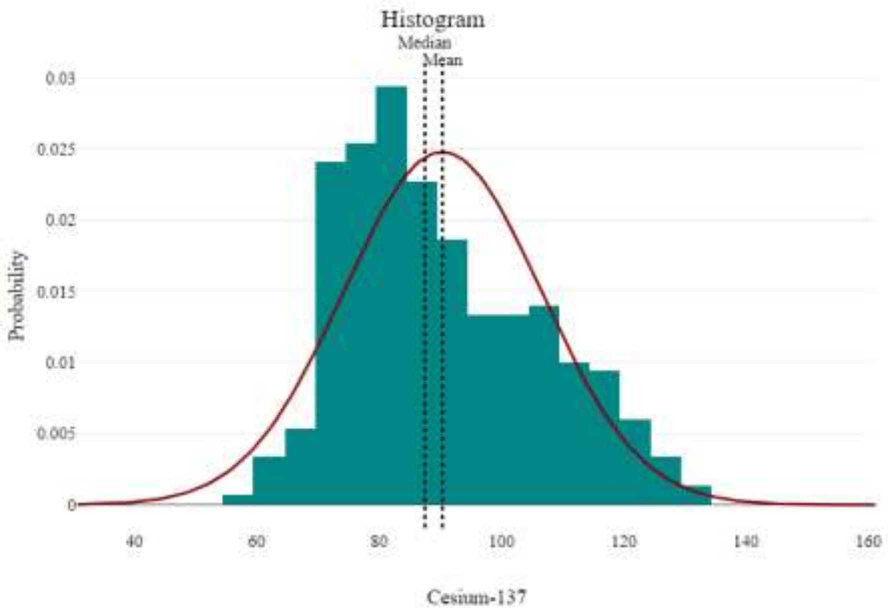

Figure (2). Histogram for ^{137}Cs source.

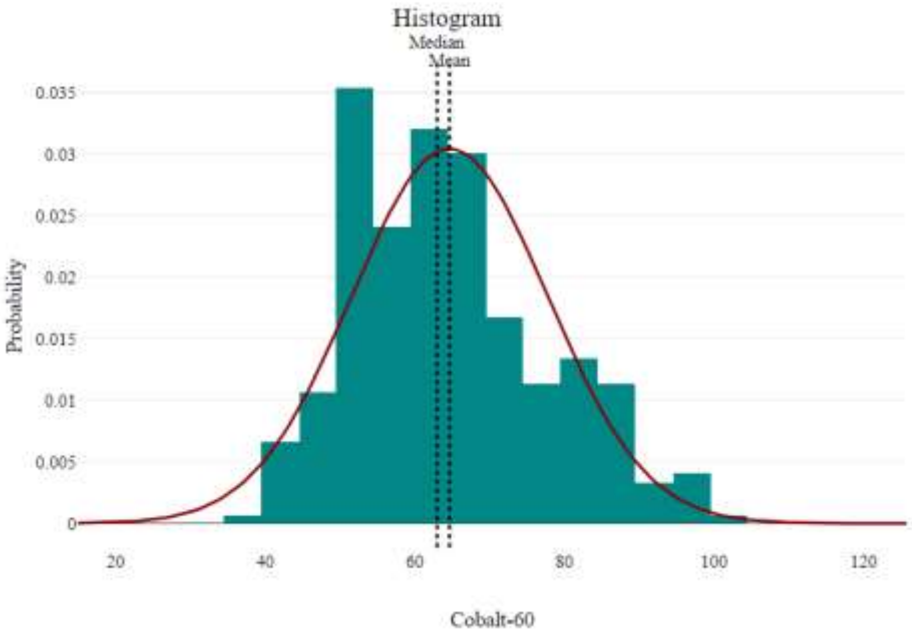

Figure (3). Histogram for ^{60}Co source.

A box-whisker plot, also known as a box plot, is a graphical representation that illustrates the location, variability, and outliers of a dataset. The box plot displays a limited number of significant values, namely the minimum value, the first quartile, the median, the third quartile, and the maximum value. Figure (4) shows the box plot for the count of ^{137}Cs and ^{60}Co in the present work. In Figure (4), if the medium of the ^{137}Cs source is located in the lower part of the box, it is probable that the data exhibit a left-skewed distribution. The middle location of the medium for the ^{60}Co source indicates that the data set follows a normal distribution and exhibits symmetry.

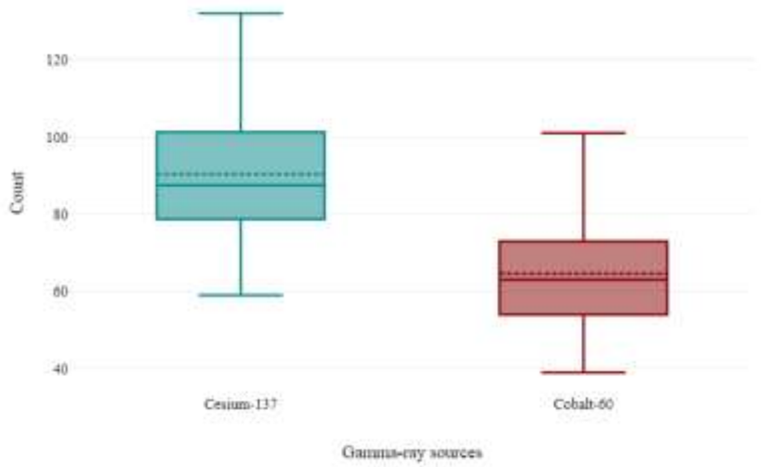

Figure (4). Boxplot of two gamma-ray sources in the present study.

VI. Conclusions

The in-situ measurement of natural gamma radiation was conducted at the University of Kufa, Department of Physics, Iraq, using a fully calibrated Digital Geiger Muller counter model. The measurement was statistically correlated with the energy of chosen sources using a Gaussian distribution. The result of the statistical parameters such as Variance, Standard Deviation, and Standard error for ^{137}Cs is larger than for ^{60}Co Also, it is found that according to the histogram and box plot, the count for ^{137}Cs is near in normal distribution while the distribution of ^{60}Co is exactly normal. This variation may be due to their energy. This work has the potential to provide a foundation for future reference and additional investigation in the field of nuclear physics measurement and experimentation.

VII. References

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