Measurement of dead time of detector using the attenuation law-based method.

Mohd Tabish, Unnati Gupta*, Archana Yadav, Sutanu Bhattacharya and Alpana Goel
Amity Institute of Nuclear Science & Technology, Amity University Uttar Pradesh,
Noida - 201313, INDIA, * email: ugupta@amity.edu

Abstract: Radioactive decays are completely random processes, for accurate detection and quantification of information regarding the source and its strength, we must understand the limitations of our detection systems. The time required to process and enable their detection as two distinct ones are determined as the dead time of the counting system. This comprises all the counting losses taking place due to the detector, and the associated electronics. Two famous models, namely Paralyzable and non-Paralyzable have been determined to predict detector behaviours to some accuracy, but none of them have proved to be perfect. The determination can be useful in determining the detection system’s efficiency, which is of prime importance for the detection and verification of nuclear materials. Some studies have been conducted and reported with the combination of both the models and the attenuation method of dead time determination. Literature review reveals this could be a probable alternative to the existing decaying source and two-source method. While this has the advantages of the non-requirement of a short-lived source and minimal variation in geometry that is incident in the two-source method. In this study, the attenuation method determines the detector's dead time with shields of various thicknesses. It is ensured that the Buildup factor is not significant in any of the cases. We have used the Canberra provided basic Labkit having a 2″×2″ NaI(Tl) detector with the Osprey-based pulse processing system. The spectra were collected with GENIE 2000 spectroscopy software. It has been observed that as the shield's thickness increases, the detector's dead time increases. This might be explained by the fact that more thermalization of the fast photons is causing more photons to fall on the detector for pulse processing. It also further suggests a minimum thickness that can be employed for the minimal dead time of the setup under consideration.

Key words: dead time, NaI(Tl), detection,

1. Introduction

Radioactivity and its associated signatures help in the identification of radioisotopes [1]. The detection and quantification require detectors to convert the energy deposited to signals which can be analysed. The conversion of this energy into signals that can sustain through the electronics requires that there should be minimal losses or attenuation while the signal travels through various components like a preamplifier, amplifier, Single Channel Analyzer /Multi Channel Analyser [2]. The processing of the signal through various components suffers from losses like dead time, pulse pile up and baseline shift, which enables reduced counting rates. The dead time is an important contributor the signal losses, which have inputs from detectors and associated electronics. This is the minimum time which must separate two events to enable them to be detected as two distinct events. Mostly, the detector dead times are in microseconds and might not be significant in laboratory conditions. But while we are using the detectors in case of any spillage or outbreak, the efficiencies of our detectors gain importance [3]. The problems of pile up or missed counts may induce errors of misinterpretation or underestimation of the quantities of radioisotopes present. While dealing with both safety and security aspects the accurate determination of quantities of radioactive is particularly important. There are methods like two sources and decaying source present to estimate the dead time also some idealised models help estimate detector time namely Paralyzable and non-Paralyzable [4,5] extensively studied. No single model however can predict the accurate dead times, yet there have been efforts to improve them and have better accuracy. The two-source method requires two semi-circular sources of equal strengths along with two dummy sources to preserve the geometry of the experimental arrangement. The sources for which this type of arrangement is found are usually short-lived and expensive to procure. On the other hand, the decaying source method requires a short-lived high-activity source, which further requires an irradiation facility nearby for the methods applicability. To cover some of these problems a novel method utilizing the attenuation coefficient is being explored. There have been studies in this regard with a similar kind of arrangement. The shielding thicknesses used are such that the build-up factor is not significant. Both the Paralyzable and non Paralyzable models are used to estimate the dead time of the counting system. The details of the formula have been provided in subsequent sections of this paper. It is a trial and extension of the two models with scintillation-based spectrometers. While it is also to be noted that the significant dead times as witnessed in gas-based detectors are not replicated in solid-state detectors due to the solid medium of detection. But when the source strength increases the pulse processing takes time and there can be significant dead times expected. To verify the same shields will be added of smaller thicknesses and the count rates are analysed. A discussion about the models and the respective formula that are used to determine the dead times is given in the following section. Further, the experimental setup has been described in section 3 and the results obtained are given in section 4 of the paper

2. Dead time model and its determination.

To correct the count losses several models are reported in the literature [1-5] for G M Counters. Among these two are the most recommended model, one is the paralyzable model and the non-paralyzable model. The paralyzable model assumes that during the dead time, no further radiation event is recorded. If m is the true count rate, n is the observed count rate and τ is the dead time of the detection system. Hence, the mathematical expression for the paralyzable model is given by the relation $m = ne^{-n\tau}$. While in the non-paralyzable dead time model, it is assumed that after a fixed dead-time the detector is recovered and mathematically expressed as $m = \frac{n}{1+n\tau}$. Moreover. It has been reported that the behaviour of the detection system lies between both the model. further, by including both the dead times a hybrid model was suggested by Lee and Gardner in 2000[6]. For the determination of the dead time, in general, two methods have been used, one is the two-source method, and another is the decay source method. The details of these two methods are given elsewhere [5]. In the present work, the paralyzable and non-paralyzable deadtimes for the scintillation detection system are determined by employing the Beer–Lambert law of photon absorption. If a beam of the photon of intensity I_0 falls normal to the beam axis and passes through the material of thickness dx, an amount of intensity reduces through the material due to all kinds of interactions namely, photoelectric effect, Compton scattering and pair production, this absorption is depending on the energy of the incident photons. If μ is the total mass absorption coefficient for a material. The intensity I_0 reduced by a factor $I_0 e^{\mu dx}$. The determination of non-paralyzable and paralyzable dead time the expression is given in the following, respectively.

$$n_0 \, \tau = \frac{m_1 \times e^{\mu . dx} - m_0}{(m_{0} - m_1)} \qquad (1)$$

$$n_0 \, \tau = \frac{\ln\left(\frac{m_0}{m_1}\right) - m \times dx}{e^{-m.dx} - 1} \qquad (2)$$

Where, n_0 is the number of photons falling on the detector, m_1 is the number of transmitted photons and m_0 is the number of photons measured by the detector.

3. Experimental details and measurements

The experiment was carried out at Amity Nuclear Security Education Training and Research Facility (AMSETRF), Amity University Uttar Pradesh, India. For the measurement and validation of the dead time of the detector an Osprey based scintillator detector (NaI(Tl)) was used, the detector was supplied by the CANBERRA. The standard ^{137}Cs gamma sources supplied by BRIT in Dec 2021 ~111kBq were used. For the attenuation, the gamma- rays of 662 keV were used, and gamma-ray attenuation measurements were taken using ~0.049 to 0.19 cm thick lead absorbers. Thicknesses [7] of the absorber are also determined by the exponential decay law; as the narrow-beam gamma-ray penetrates materials, the attenuation of the intensity (I) of gamma rays obeys the exponential decay law of nuclear radiation can express mathematically as,

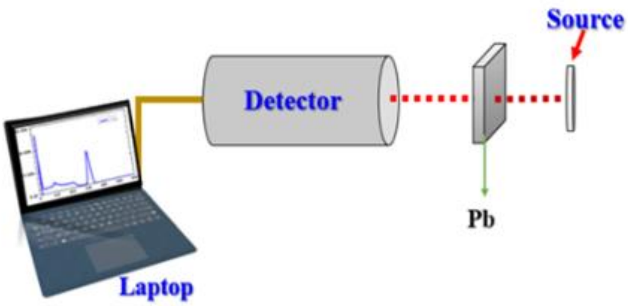

Figure 1: Experimental Setup for the measurement of dead time.

$$I = I_0 e^{-mdx}$$

Where I and I_0 are the intensities of the gamma-rays before and after attenuation, m is the absorption coefficient [3] of the material and dx is the thickness of the material. For the measurement of the thickness dx, the gamma-ray energy of 834.84 keV of ^{54}Mn was used, as Olshanoski et al., [2] suggested that gamma-ray energies ranging from 800 to 1400 keV is sensitive to density thickness. Hence, for the thickness measurement, 834.84 keV has been used and the mass attenuation coefficient [3] in Pb is 0.026 cm^{-1} The absorber was placed between the source and detector in the same plain. The measured thicknesses along with the number of counts before and after absorption are given in Table 1

Table 1. The number of counts recorded in 100s, and activity recorded after attenuation along with the average measure thickness of the Pb (ρ=11.34 g/cm^3) absorbers.

S. N.	Pb foil	Counts (I_0)	Counts(I)	Thickness (cm)	Average Thickness (cm)
1.	Pb-11	48498	46772	0.053	0.049
2.	Pb-12	48498	46772	0.053	
3.	Pb-13	48498	47176	0.041	
4.	Pb-21	48498	46150	0.073	0.073
5.	Pb-22	48498	46200	0.071	
6.	Pb-23	48498	46130	0.073	
7.	Pb-31	48498	43840	0.148	0.135
8.	Pb-32	48498	44373	0.130	
9.	Pb-33	48498	44452	0.128	
10.	Pb-41	48498	42594	0.191	0.190
11.	Pb-42	48498	42594	0.191	
12.	Pb-43	48498	42643	0.189	

Further, the experimental setup was calibrated using the ^{137}Cs and ^{60} Co standard gamma sources. To see the effect of the absorber's thickness on dead time, the Pb absorbers of the various thicknesses were considered, these thicknesses are mentioned in the Table 1. Further, the spectrum using each thickness were recorded for 15 min, for the 661.657 keV gamma ray of ^{137}Cs source before after attenuation using Pb absorbers of the thickness 0.049, 0.073, 0.135 and 0.190 cm respectively. The observed spectra are shown in Figure 3.

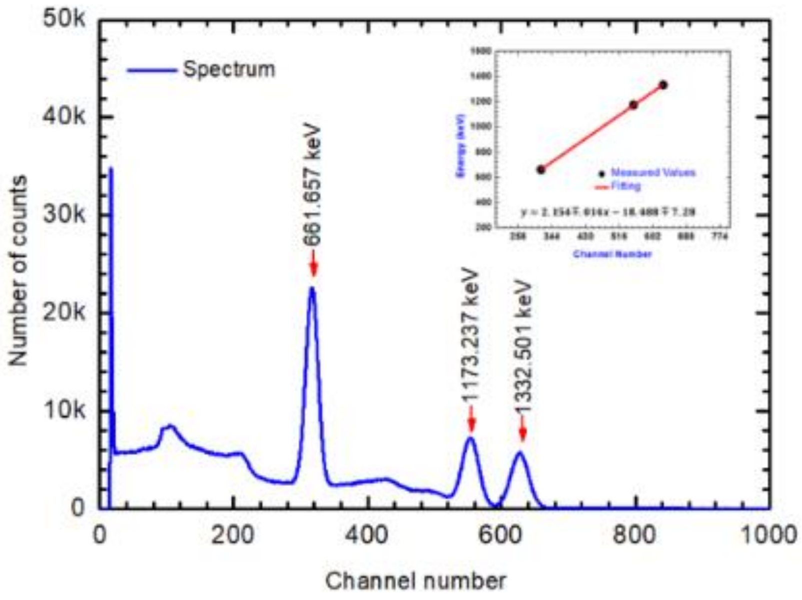

Figure 2. Calibration of NaI(Tl) detector using gamma ray energies of standard sources ^{137}Cs and ^{60}C0.

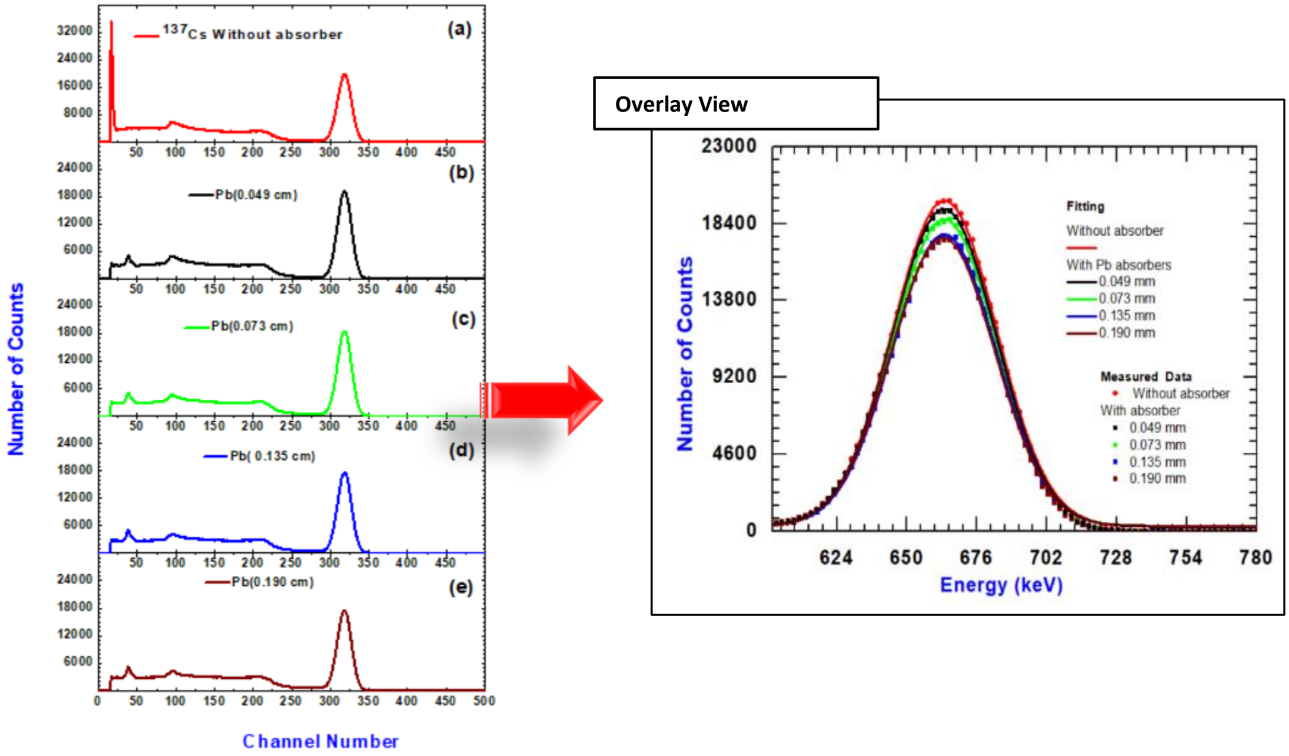

Figure 3. The observed spectrum of ^{137}Cs using different absorbers of different thicknesses alongwith overlay view of the peaks

Table 2. Paralyzing and non-paralyzing dead time of the scintillation.

Mass attenuation coefficient (cm^2/g)	Thickness (cm)	Counts without absorber	cps(w/o) m_0	Counts with absorber	cps(w/a) m_1	Paralyzing Dead time (s)	Non-Paralyzing Dead time (s)
0.1001	0.049	19517	65.06	19438	64.793	7.046×10^{-05}	9.674×10^{-04}
0.1001	0.049	19517	65.06	19063	63.543	4.386×10^{-05}	1.037×10^{-04}
0.1001	0.049	19517	65.06	19364	64.547	6.525×10^{-05}	4.616×10^{-04}
0.1001	0.073	19517	65.06	18588	61.960	3.173×10^{-05}	5.398×10^{-05}
0.1001	0.073	19517	65.06	18294	60.980	1.692×10^{-05}	2.169×10^{-05}
0.1001	0.073	19517	65.06	18159	60.530	1.005×10^{-05}	1.155×10^{-05}
0.1001	0.135	19517	65.06	17509	58.363	2.538×10^{-05}	3.720×10^{-05}
0.1001	0.135	19517	65.06	17517	58.390	2.560×10^{-05}	3.770×10^{-05}
0.1001	0.135	19517	65.06	17519	58.397	2.566×10^{-05}	3.782×10^{-05}
0.1001	0.190	19517	65.06	17350	57.833	3.737×10^{-05}	6.867×10^{-05}
0.1001	0.190	19517	65.06	17312	57.707	3.654×10^{-05}	6.591×10^{-05}
0.1001	0.190	19517	65.06	17304	57.680	3.637×10^{-05}	6.534×10^{-05}

4. Result and Discussion

The range of the dead times obtained from the two models is in concurrence as shown in Figure 4. No specific trend is seen in the variation of dead time as the thickness of the shields is varied. It is evident that the predicted dead times are somewhere between the values estimated by the paralyzable and non-paralyzable models. At low thickness, the latter exceeds the former and that can be explained by the fact that due to intense radiations falling on the detector, it is inactive for a longer time and takes a lot of time to process the previous pulses. Based on the analysis, it can be predicted that the suitable thickness of absorber which can be used with the attenuation method is between 0.07-0.15cm. the results from both methods are in good agreement. Further, this work can be expanded and the effect of increasing the source strength can be seen in the dead time of the counting system.

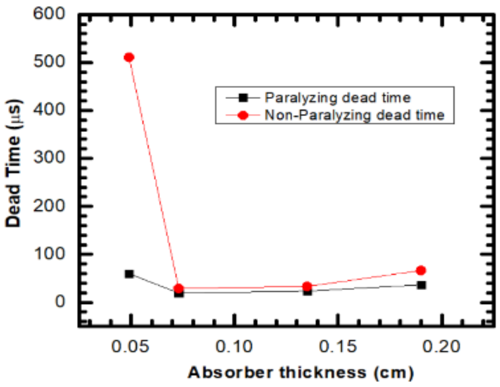

Figure 4. Paralyzing dead time and non-paralyzing dead time with respect to the thicknesses model.

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