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Decaying source model: Alternative approach to determination of true counting rates at X and gamma ray counting systems

S.M. Karabidak [a,*], U. Cevik [b]

[a] Gümüşhane University, Faculty of Engineering and Natural Sciences, Department of Physics Engineering, Gümüşhane, Turkey
[b] Karadeniz Technical University, Sciences Faculty, Department of Physics, Trabzon, Turkey

HIGHLIGHTS

- A new approach for correction of the dead time caused by the counting system has been proposed.
- The dead time caused by the counting system electronics were taken into account.
- The proposed model was seen to provide an effective correction in counting rates with fluctuations.
- Simulation and experimental study next to the proposed theoretical model were performed.
- Theoretical and simulation results showed good agreement.

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ABSTRACT

The counting systems consisting of electronic devices are used for detection of radiation due to X or gamma rays. The dead time of the counting system is based on time limitations of these electronic devices. The dead time causes counting losses. Determination of counting rate losses in quantitative and qualitative analysis become a vital step for correction of analysis. Therefore, compensating for counting rate losses is of great importance. These counting rate losses are due to piled up reject time, paralyzable or non-paralyzable system dead time or a combination of these mechanisms. Paralyzable and non-paralyzable models are well-known and frequently used for correction of counting rate losses dependent on the system dead time. However, these two models do not provide enough correction at medium and high counting rates. Therefore, the new models for corrections of counting rate losses are needed. For this reason, both an alternative approach is proposed and a simulation program is coded for counting rate losses in this study. A good agreement is obtained between theoretical model and simulation program.

1. Introduction

Recording two pulses apart as two different events at almost all detectors systems requires to be separated from another pulse. This situation needs the minimum time interval. The minimum time interval based on electronic devices using the counting system is usually called the dead time of the counting system. This is generally determined by pile up reject time, paralyzable (extending) or non-paralyzable (non-extending) system dead time or a combination of these mechanisms (Pommé, 1998). The photons arriving to the detector at the dead time period are not being counted. Thus, count rate which is expressed as the count of per unit time decreases.

In correction of the counting rate, two models of dead time behavior of the counting system have come into common usage: paralyzable and non-paralyzable (Knoll, 2000). To generate second output pulse without a time interval of at least τ between two consecutive true events is not possible in paralyzable model. In this model, the recovery of the electronic device is further extended during the respond time τ to an initial event for an additional time τ by some additional true events which occur before the full recovery has taken place. In non-paralyzable model, recovery period of electronic device is not affected by events that have come into being during the τ dead time (Evans, 1955). These two models are assumed to express the idealized behavior. Every true event came into being during live time of detector was assumed to occur in a stable τ dead time at every two models (Knoll, 2000). However, this

* Corresponding author. Tel.: +90 456 2337425x1121; fax: +90 456 2337427.
E-mail addresses: smkarabidak@gumushane.edu.tr, salihm@ktu.edu.tr (S.M. Karabidak).

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situation is only valid in the dead time depending on peaking time of amplifier. But a counting system can be containing analog digital converter (ADC) which determines the energy value of pulse. The dead time of such a counting system is variable with ADC conversion time (Karabıdak et al., 2009). Therefore, fulfilled corrections which are taken into account for a fixed dead time can not be realistic. Also, modern counting systems consist of electronic devices which contain paralyzable (amplifier), non-paralyzable (ADC) and pile-up reject (amplifier) (King and Lim, 1985).

Paralyzable and non-paralyzable models predict the same first order losses, and differ only when true event rates are high. These models are two extreme idealized system behaviors, and real counting systems often display a behavior that is intermediate between these extremes. The detailed behavior of a specific counting system may depend on physical processes taking place in the detector, delay introduced by the pulse processing and recording electronics. In non-paralyzable and paralyzable models, rate of true events correspond to rate of observed events is described in the literature (Evans, 1955; Gardner and Liu, 1997; Knoll, 2000; Gilmore and Hemingway, 2003).

In medium and high count rate events, both of the two models are not applicable. The corrections which are done by these models are problematic because of the limitations expressed below. The troubling aspect of non-paralyzable model is the singularity at $m\tau = 1$and the fact that a maximum observed counting rate of $1/\tau$ is approached in the limit as n approaches infinity. In paralyzable model, the observed counting rate becomes zero at high count rate. Also, it should be noted that this model cannot be explicitly solved for n_0. But this model solves a transcendental equation to obtain the true counting rate. In addition, the observed counting rate is either double valued or does not exist above a maximum value given by $\exp(-1)/\tau$ (Gardner and Liu, 1997; Karabıdak et al., 2009).

A few correction methods based on the live time because of these limited of non-paralyzable and paralyzable models have been proposed in the literature: loss-free counting (Harms, 1967; Westphal, 1979, 1982) and zero dead time (Upp et al., 2001). Statistical analysis related to these correction methods were made by a few researchers and a number of deficiencies of these correction methods were identified (Pommé, 1998, 1999, 2001, 1999; Pommé et al., 1999; Pommé, 1999; 2001; 2008).

Little is also known about the characteristic of the count loss due to saturation effects in detector, amplifier and ADC under a high counting rate situation (Choi, 2009). Such a study to investigate the behavior of a gamma and neutron scintillation counter in high energy gamma and neutron fluxes was fulfilled by Hashimoto and Yamada (1999) for the dead time with paralyzable type using experimental and theoretical approach. In this regard, this study may pioneer in a saturation effects studying for the dead time existing in counting systems that has a specific detector and electronic devices.

The previous work by Karabıdak et al. (2009) is based on a measuring principle on the total live time. This model can be applied to the counting systems at which system dead time is not predominant on count rates. That is, this method adequately corrects counting lost at steady counting rate. Also, the dead time or count rate corrections based on live time can be ideal in the count rates which are not predominate at the system dead time. In addition, on a mathematical essence, the principle of the live time is an integral mathematics. The integral mathematics is correct if applied only to stationary Poisson processes (invariable in time). It should be noted that time-invariant Poisson processes are valid in experimental studies with radionuclides having long half-lives. The current study includes count rate corrections based on differential mathematics, and the proposed model in this study is ideal in the count systems at which the system dead time is predominant on count rates. Differential mathematics is also correctly applicable to Poisson process changing in time.

2. Experimental arrangement

The powdered marble pressed into tablets of 13 mm diameter have been obtained the absorber samples. To experimentally determine the mass absorption coefficients of these materials, radioactive point sources with energies ranging from 80 to 1333 keV (^{109}Cd, ^{57}Co, ^{133}Ba, ^{22}Na, ^{137}Cs, ^{54}Mn and ^{60}Co) was used. To reach the detector as a parallel beam of gamma rays released by these sources, prevent unwanted scattering, and place the sample and resources, lead collimators on 1 mm diameter holes were used. The first measurements were taken without the sample. Then, the same procedure was performed by placing the samples between the source and the detector. The geometry of the experiment used in the measurements is shown schematically in Fig. 1.

A Canberra High-purity Ge (HPGe) detector (GC 1519 model) with a resolution of 1.9 keV at 1332.5 keV, Genie 2000 spectroscopy software, preamplifier (Model, 2008), of Canberra instruments, Tennelec TC 244 spectroscopy amplifier and Multiport II ADC and MCA of Canberra instruments were used to count gamma-ray photons emitted by source and gamma rays photons passing through the samples. The structure of the Gamma-Ray spectrometry system used in the measurements is shown schematically in Fig. 2.

3. Counting rate model

A correction method that included to a statistical approach for Geiger–Muller counter was proposed by Kurbatov and Mann (1945). All of photons emitted from source are assumed to be caught by the detector and transmitted to counting system without loss. **Let $P(t)$ be the probability that a photon is emitted from a source in the interval $(t-\tau, t)$.** Let $a(t)dt$ be the probability that a photon is caught by detector and transmitted to counting system during the interval $(t, t+dt)$. The fact that $P(t)$ is a continuous function of t is used here. In order that a photon can be caught by the detector and sent to counting system, it is necessary and sufficient that; (i) a photon is sent counting system from detector in the time interval $(t, t+dt)$, and (ii) no counting take place in the time interval $(t-\tau, t)$. Since these are independent events, the realization probability of one counting in the time dt becomes $[1-P(t)]a(t)dt$. Then, since only one counting can occur in the interval $(t-\tau, t)$, the probability of one counting in that interval is (Kurbatov and Mann, 1945):

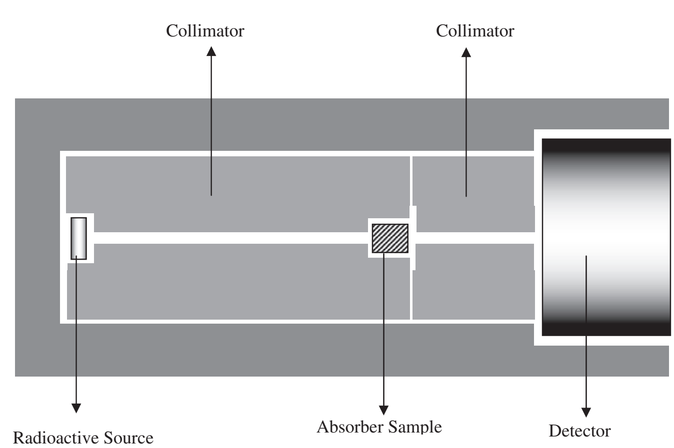

Fig. 1. The geometry of the experiment.