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Determination of Appropriate Source-to-Detector Distance Dependence of Gamma Spectrometry System to Achieve Higher Resolution

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Operation of gamma spectrometry requires intensive monitoring of gamma ray fluxes. When a radioactive intense source is placed close to a crystal detector, it becomes saturated as a result of detector dead time. On the contrary, when placed far away, there is loss of count statistics. For this reason, optimal position for placing the source has to be investigated. With the improvement in the instrumentation of radiation detection applications over the years, high count rate measurement accuracy is more crucial than ever. This is due to periodic measurement and new correction models for dead time. The aim of this study is to examine the performance of two gamma spectroscopic systems. The source detector distance dependence on dead time, peak-to-compton ratio, overall amplifier gain, FWHM, and voltage variation were investigated using American standard procedures (ANSI/IEE -325). Measurements were performed at five (5) different distances of detector cap for four (4) point sources (Co-60, Eu-152, Cs-137 and Ba-133). Source-to-detector distance at 25 cm was improved to avoid summing coincidence and dead time correction. The results obtained at 25 cm showed that the dead time was found less than 1% as compared to 4 cm. This will describe the stability of dead time. It also indicated that for both detectors the rise in biased voltage will yield a good resolution at 1332.5 KeV. This study is significant as it provides information to ensure that detectors are kept at optimal distance to achieve good dead time.

Keywords: HPGe detectors; FWHM; Dead time; Peak-to-Compton ratio; Point Sources.

1. Introduction

Researchers around the globe have been focusing on correction of dead time and pileup loss phenomena in radiation detectors' measurement. As a result of the random nature of radioactive decay, there is always probability of losing true event because it occurs quickly on a preceding event (Knoll, 2009). Related problem of file-up is often confused with dead time phenomenon. Usually, when higher count rates are encountered there is possibility of severe dead time in the system. For an accurate measurement of the system dead time must be take into account. This is the minimum time required to separate two events in order to record two signals by the system. In most cases this may arise due to associated electronics. Dead time in radiometric context refers to paralysis or resolving time (Gilmore, 1996).

Many researches have been attempted to develop a new model for dead time of gamma ray spectrometry systems (Usman & Patil, 2018). Signal counting in random process is unavoidably affected by losses. The dead time technique correction models is important to review our existing radiation detection system. In addition, Physical measurement such as detector design, geometrical shape, high voltage, operating temperature and pressure are highly contributing to the ballistic effect of dead time (Smith & Kearfott, 2018).

However, in gamma spectrometry system there are three (3) consequences that contributes to the effect of dead time, this is either by internal loss in the detector (reducing the height of the pulse), loss occur by the system circuitry (shaping time of the spectrometry amplifier) or by data acquisition (conversion of the analogue

to digital converter (ADC)).When the signal arrives at the input gate, the ADC is inactive, then the gate will open so that signal will pass to ADC and the conversion will begin. It is possible to find the optimal position place a detector and the source. This will minimise such effect by chosen a well-defined distance from the source (Drahansky, 2016, Usman & Patil, 2018). A typical counting system is shown in Figure 1 which gives overview of schematic diagram associated with electronic units. Counts are lost due to finite respond of the successive components in the counting system Viz: detector, preamplifier, amplifier, ADC and MCA.

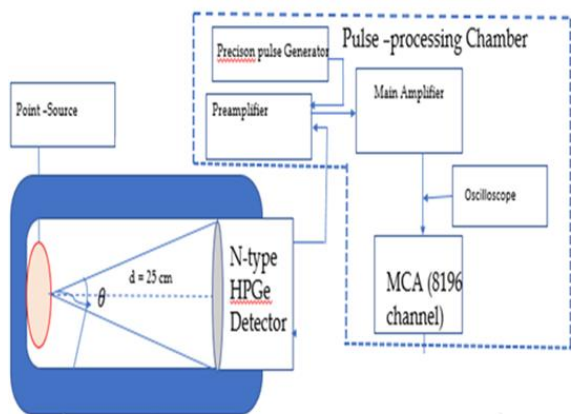


Figure 1. Schematic block diagram of pulse processing chamber of HPGe detector

All the multichannel analyzer reimburse for ADC dead time by gating the live- time clock off during conversion. Then, Compensation can be basically perfected. On the other hand, pile-up (summing effect) losses, may be equally important source of inaccuracy on gamma spectrometry system (Usman & Patil, 2018). In most common radiation detectors small signal will last for a fraction of microseconds.

In this research, the dead time of a Gamma spectrometry system will be measured by varying the distance of a point source. This is to determine the perfect working of pulse processing electronic components of gamma spectrometry system. This will help to effect correction when need be carried out. Amplifier will be varying against gain conversion factor to terminate the effect associated with electronic noise and shift of pulse. The full width half maximum (FWHM) will also be measured to ensure good resolution for the two working HPGe detectors by ensuring a good source-to-detector distance. In this research work, the energy ranges from 81.0 KeV to 3194.9 KeV was considered.

1.1 Theory:

Technically, the time during which the analogue to digital converter input gate (ADC input gate) is closed is called dead time (DT) and not surprisingly when the time is open it is referred to as live time (LT), while the normal physical time is known as real time (RT) sometimes called Clock time (CT) or True time (TT). Their relationship can be express in Equation(1) (Gilmore, 2008).

$$DT = RT - LT \dots \dots \dots (1)$$

Basically, MCA system will present the dead time as the count progressive in percentage. In old systems, it uses channel “0” to count for live time and “1” for real time pulses. While of recent MCA system, separate registered are used.

$$DT = (RT - LT) / RT \times 100 \dots \dots \dots (2)$$

1.2 Dead time models

In radiation detection system dead time can be classified by paralyzable and non paralyzable behaviour (Karabidak, 2017). Paralyzable behaviour of a detector system can be affected by the radiation even if the signal is not processed, this usually occur as a result of delay in detector or electronic components’ response While non- paralyzable or fast detector, the system is not affected even if the signal is not processed. The dead time responses to random rate input signals are show in Figure 2.

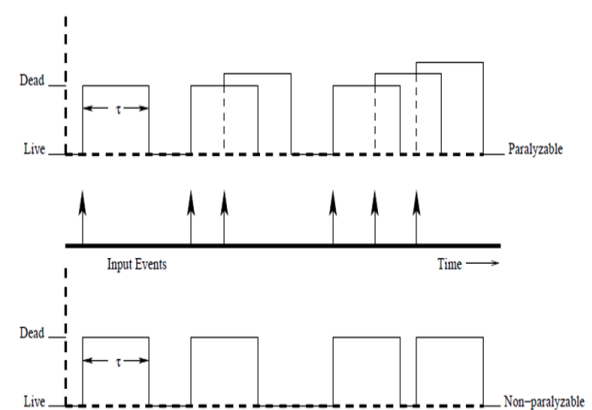


Figure 2. Illustrate the paralyzable and non-paralyzable dead time behavioural models (Knoll, 2009).

To measure the effect of a non-paralyzable system, let the input rate by a device be λ_{in} and assume the time interval between rate is exponentially distributed. Then the system will lose a fraction of input rate due to dead time and

produce an output rate λ_{out} . The loss of this rate can be expressed in Equation 3 (Muller, 1973).

$$\lambda_{in} - \lambda_{out} = \lambda_{in} \tau \dots \dots \dots (3a)$$

$$\lambda_{out} / \lambda_{in} = 1 / (1 + \lambda_{in} \tau) \dots \dots \dots (3b)$$

On the other hand, the key observation with the paralyzable system is that the output rate is equal to that portion of the input events with the interarrival time (t) that are greater than dead time (τ) as indicates in Equation 4

$$[\lambda]_{out} = \lambda_{in} \cdot P(t > \tau) \dots \dots \dots (4)$$

If the event arrives at random interval, then the probability of n events arriving within the time interval (t) obeys Poisson distribution is given in Equation 5.

$$P(n) = \frac{[(\lambda t)]^n}{n!} e^{-(\lambda t)} \dots \dots \dots (5)$$

By integrating the probability density function associated with Poisson distribution $P(t) = \lambda e^{-(\lambda t)}$ will yield average output rate for paralyzable dead time behaviour in Equation 6.

$$\lambda_{out} = \lambda_{in} e^{-(\lambda_{in} \tau)} \dots \dots \dots (6)$$

The average input rate versus the average output rate for both the paralyzable and non-paralyzable dead time model is shown in Figure 3. It is seen that at low input rates the two models show almost identical behaviour while, at higher input rates the two models differ extensively.

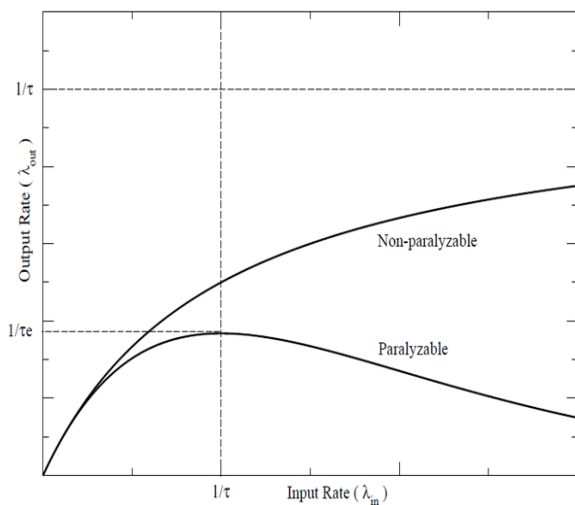


Figure 3. Variation of input and output signal for the two models (Knoll, 2009)

1.3 Effect of dead time

All components in the detector system contribute to dead time. This occurs from the detector crystal up to electronics components that process the signals. Generally, dead time affect the three major parts of the experimental data viz: output count rates (reduction of count rates through the loss of inputs events), event range densities (the interval density perturbation caused by the present of dead time will invalidate any assumption made as the Poisson-nature of the input signals yield $t < \tau$) and event count statistics (effect of distorting interval distribution of the incoming events of assumed exponential distribution i.e. $\lambda_{in} \tau < 0.2$).

2. Materials and Methods

2.1 Materials

In this study, source detector distance and amplifier conversion factor were achieved using high resolution n-type (CG 2018 model) and p-type (GEM-25-25-76-LB-C) co-axial closed end gamma ray spectrometry system with relative efficiency 20% and 25% with respect to 3x3 cylindrical sodium iodide (NaI) detector. It was connected to 16384-channel Multichannel Analyser (MCA). The spectrum obtained from MCA is analyzed using the Genie 2000 software obtained from Canberra and Gamma vision software from Ortec product. The detectors have energy resolution of 1.8 KeV and 1.85 KeV. And operates at 3.0 kV and 4.0 kV, at least 1000 counts were accumulated in 1332.5 KeV to avoid summing coincident ray. The coarse gain and fine gain were adjusted with shaping time 4 μ s and 6 μ s for n-type and p-type respectively. In order to reduce the background level of the system, the detector is shielded using 6 cm lead on all sides.

The four (4) different radiation sources, ¹³⁷Cs, ⁶⁰Co, ¹³³Ba and ¹⁵²Eu, that give 81.0, 121.8, 344.3, 661.6, 1173.2, and 1332.5 keV gamma ray energy was placed at axial locations with respect to the detector axis, at 5 different distances (4, 8, 12, 20 and 25cm) from the face of the detector and the measurement was performed for each source for a period of 1 hr to obtain good value in the evaluation of each gamma peak. The same radio nuclides was used in the calibration process of the detector. The sources' activities, reference date and the half-life values of the studied radioisotopes and gamma ray emission probabilities per decay for all radioisotopes used in the work are listed in Table 1. The point source was made by Eckert & Ziegler isotopes product (US.RSC).

Table 1. Information data of the radio nuclides used in this experiment

Nuclide	Energy (KeV)	Emission Probability (%)	Activity (Bq)	half life (Years)	Reference date
¹⁵² Eu	121.8	25.6	-	13.57	
¹³³ Ba	302	18.33	3023010.55		
¹³⁷ Cs	661.7	85.1	34408	30.1	
⁶⁰ Co	1332.5	99.98	24455	5.27	01/10/ 2017

2.2 Source detector geometry

According to inverse square law, the count rate (R) is varying with the distance from the detector cap (Knoll, 2009). This can be express in Equation (7).

$$R \propto 1/d^2 \dots\dots\dots(7)$$

where, R is the radius of the crystal and d is the distance between source and crystal.

The source -to-detector distance can be show in Figure 4

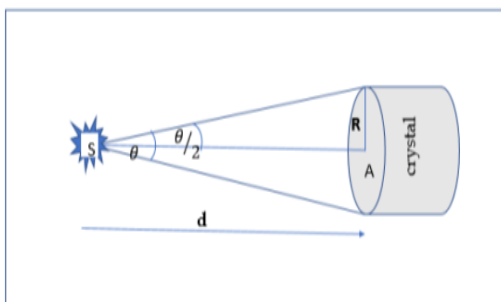


Figure 4. A schematic diagram of a source -to-detector distances

The solid angle expresses in Equation (8)

$$\Omega = A/R^2 \dots\dots\dots(8)$$

Where A is the area of the crystal cap.

3. Results and Discussion

3.1 Variation of conversion factor with amplifier gain

The energy (KeV) per channel is known as conversion factor. This is the ratio of difference between two peaks of ⁶⁰Co (1173.2 keV and 1332.5 keV) to the difference between the two peaks channels were evaluated for a different

amplifier gain. Figure 5 show variation of conversion factor and Peak-to Compton ratio with overall amplifier gain. It is observed that the noise from amplifier was minimized.

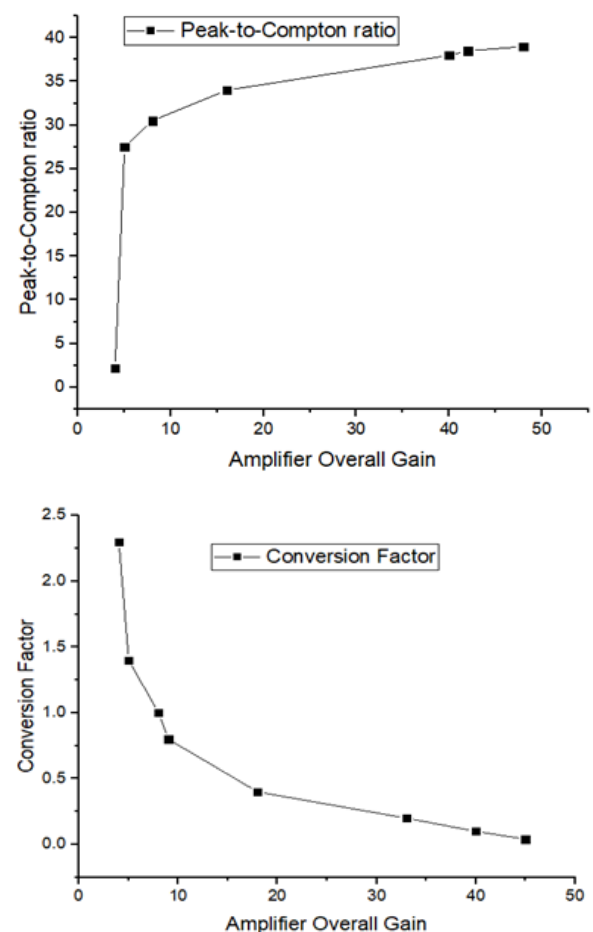


Figure 5. Variation of peak-to-compton ratio and conversion factor with amplifier overall gain

3.2 Variation of FWHM with Bias voltage

It can be observed that the FWHM of the peak improves as voltage is raised as shown in Figure 6. It is found to be about 1.75 KeV for

1332.5 KeV at 3.5 kV, while 3.3 KeV at 1.0 kV for p-type detector. For the for n-type detector it is found to be 1.85 KeV for 1332.5 KeV at 4.0 kV, while 4.2 kV at 500 Volts.

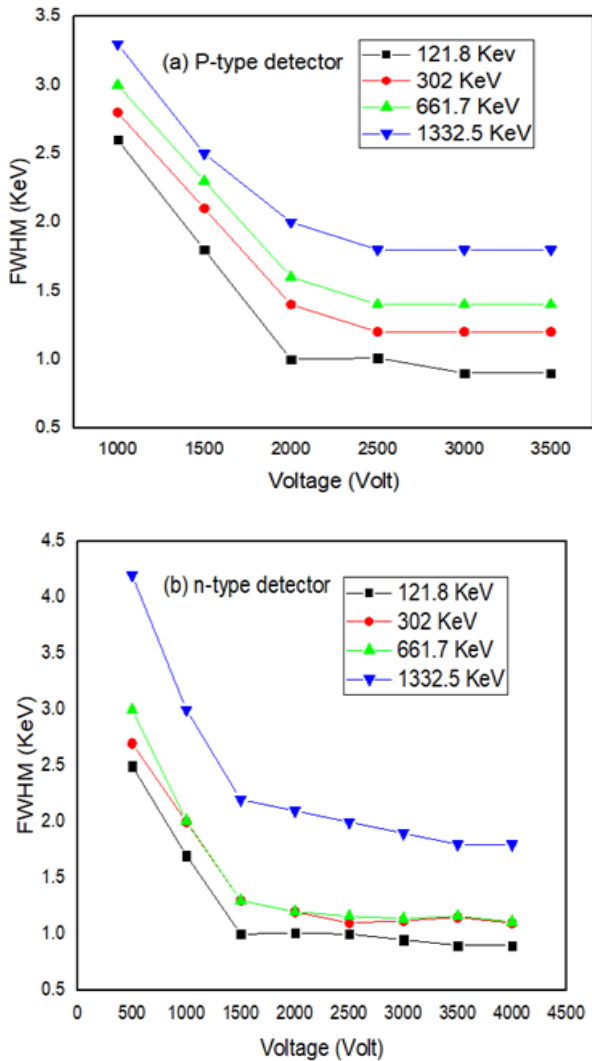


Figure 6: Voltage variation on resolution (FWHM) for n-type and p-type coaxial closed end detector

3.3 Source -to-detector distance

At a constant Source- to- detector distance, the distribution of radio nuclides materials within a volume of the material oppose to concentrate at a point source, this could decrease the gamma ray intensity. However, true coincidence summing is a geometry dependent and errors that are suffered particularly when source are positioned very close to the detector (Cooper, Amman, & Vetter, 2018; Gilmore, 2008). This effect could be mitigated by reducing the solid angle. For effective calibration, point source should not be placed close to the detector (Khandaker, Jojo, & Kassim, 2012). It is recommended to be carried out an optimum source to detector distance of 25 cm to reduce the solid angle (Institute, IEEE. 1997; Meena et al, 2017).

3.4 Variation of death time with Energy

The dead time, 4 cm from the detector cap was found to be 2.0 % and 0.7% for p-type and n-type detectors. It decreases as the distance from the detector increases by 0.5% and 0.25% at 25 cm. This indicates that the dead time decrease as the distance from detector increases for each detector as shown in Figure7. The experimental result is better represented by a second order exponential decay equation of $y = \frac{b \exp(-x/k)}{c} + c$. The parameter b and k represent the amount of dead time and peak energy resolution, where c is the stability of dead time subjected to different gamma ray energy at different distances.

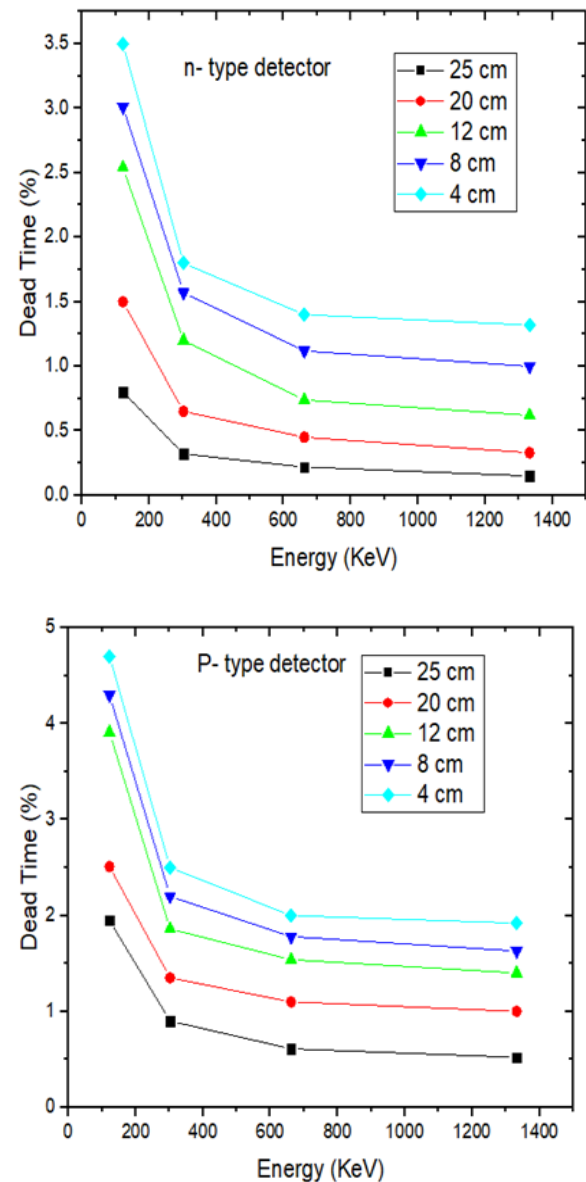


Figure 7. Relationship of dead time at different source energy -to- detector distances for n-type and p-type detector.

3.5 Variation of FWHM with detector distance

The paramount Resolution (FWHM) can be obtained by increase the distance from detector as shown in Figure 8. At 4 cm from the detector cap, the FWHM for 1332.5 KeV was measured to be 2.8 KeV and 2.5 for n-type and p-type. While, at the distance increase it found to be 1.75 and 1.85 keV at 25 cm.

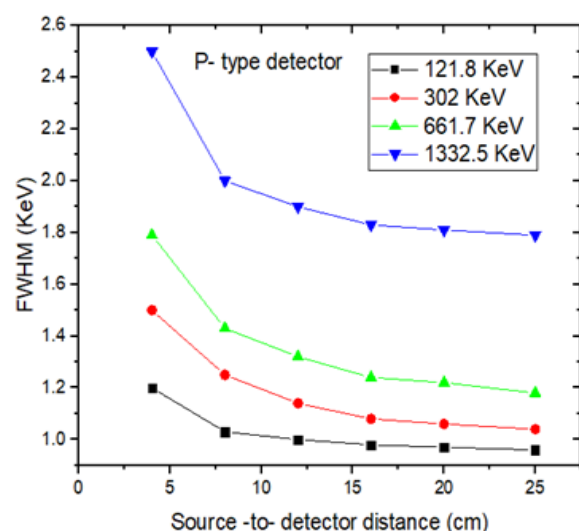
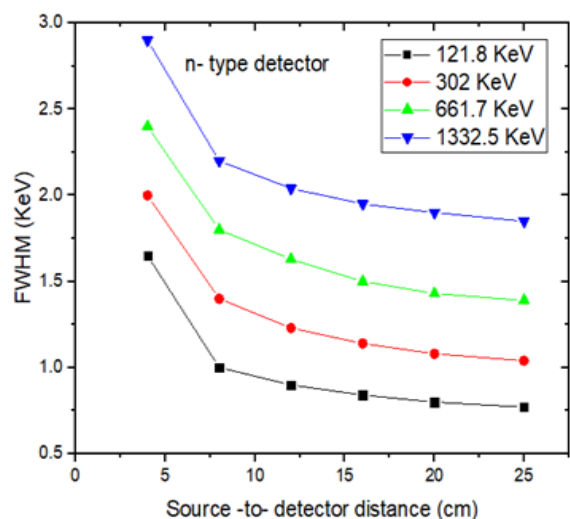


Figure 8. FWHM versus several source -to- detector distances for different gamma ray energies.

4. Conclusion

Validation measurement of the two coaxial closed end HPGe detectors using source-to-detector distance was achieved. A series of measurements were conducted using four (4) standard radioactive point sources viz: ^{152}Eu (121.8 KeV), ^{133}Ba (302 KeV), ^{137}Cs (661.7 KeV), and ^{60}Co (1332.5 KeV) positioned at five (5) different distances to the detector. Preferably placing the source distance at 25

cm is recommended to minimise the summing coincidence effect and the detector dead time. The variation of dead time with distance, indicates that the dead time effect at 25 cm is less compared to 4 cm. However, the relationship between FWHM and voltage variation show that the raise in bias voltage will yield a good resolution at 133.5 KeV for both detectors. FWHM by varying a distance was measured. The test result shows that at 25 cm the dead time is less than 1%. This is an indication of stability in the dead time of the gamma spectrometry. The outcomes of this study is significant as it ensures that detectors are kept at optimal distance to achieve good dead time.

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Conflict of interest

The authors declare that there is no conflict of interest.

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