The effect of radiation source distance to the scintillation detector based on Monte Carlo simulation

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Abstract. The variation of the source distance to the detector causes a change in the count value. The aims were to study the effect of source distance variation to a detector. This research simulated count value detected by the scintillator detector with a variety of distance to the radiation source using EGSNRC tutor.3 Monte Carlo. The Energy of ⁶⁰Co radiation source was modeled monoenergetic, so energies 1.17 MeV and 1.33 MeV are handled separately. The geometry of this source was assumed to be the point source. The simulated medium was divided into three regions, vacuum, scintillation detector, and vacuum. The range of detector distance varied from 5 to 9.5 cm from the source and used 10⁹ particles. The cut-off Energy for electrons 0.512 MeV and photons 0.01 MeV. The output score energy deposited in the scintillation detector. The count value for each region was analyzed and compared. The changes of distance from 5 cm to (5.5, 7.5, 8.5, and 9.5 cm) caused an increase of a count in the Compton area of 5.1%, 27.1%, 35.9%, and 44.6%, respectively. While in the photopeak area there was a decrease of 2.7%, 12.2%, 15.8%, and 19.0%, respectively. There was a change in count value on the distance variation caused by the quantity of source changed. The detector captures less quantity in the photopeak area.

Keywords: radiation source distance, Monte Carlo simulation

1. Introduction

In principle, radiation detection, both by measurement and simulation, utilizes the principles of interaction between radiation and materials. When radiation passes through a detector, there will be an interaction between the radiation and the detector material so that the energy transfer from the radiation coming into the detector material occurs. This energy transfer causes different types of responses from the detector material. The kind of response shown by a detector against radiation depends on the type of radiation and the scintillator detector material used.

The scintillator detector used in the research is Thallium Activated Sodium Iodide (NaI (Tl)). The detector is made of crystal and has a large mass density. This detector can be used at room temperature and has a high atomic number so that photoelectric absorption becomes a very important part [1].

The method used in the simulation is the Monte Carlo (MC) method. The MC method can simulate radiation transport in a material. Radiation transport in the content covering the particles of the particle track record was born, interact, until the death of the particles in the material. The MC method provides excellent and accurate results in calculating the response function of the detector. In the simulation with MC, we used EGSnrc software.

In EGSnrc software, has made the selection and use of data. Selection of data using PEGS4 and data usage using a program code system short tutorial response function of a detector that is tutor3.mortran. In PEGS4 data, the required material will be modeled so that it stores a lot of data and produces information in the form of data cross-section from the material. The data is stored in the pegs4.dat file. This file will be used to run the tutor3.mortran program.
In this study, the EGSnrc code [2] was used to evaluate the gamma-ray energy of each detector which would be simulated from radioactive sources of Energy were 1.17 MeV and 1.33 MeV respectively. The response of the NaI (Tl) crystal scintillator detector is used in geometry in a 3-dimensional direction in the form of cubes, where the surface width is in the XY direction defined infinitely, and the thickness of the material is 5 cm in the Z direction, the number of particle histories is 109 particles. The function of each detector response observed with varying parameters PCUT and ECUT, which is the cut-off Energy to photons of 0.01 MeV and 0.512 MeV to electrons.

1.1 Scintillation

The process of scintillation is the visible light emission during the transition of electrons from higher energy levels to lower energy levels. This scintillation process will occur if there is a vacuum of electrons in a deeper electron orbit. This electron vacuum can be caused by the release of electrons from the bond (the ionization process) or the process of jumping the electron to a higher energy level (the outer electron trajectory) because it is subjected to radiation. The greater the radiation energy received, the more empty the electrons in orbit in the interior will occur, so that the amount of light that is released will increase. This visible light will then be converted into electrical signals.

Scintillators can be solid or liquid, both organic and inorganic. Organic scintillators are used for the detection of alpha and beta, while inorganics are used for the detection of gamma and x-rays. The scintillator has a different scintillation effect for the three types of alpha beta and gamma radiation.

The properties of the scintillator needed for the scintillator to be used as a good detector are transparent to the light produced and directly proportional to gamma energy.

1.2 Photomultiplier Tube (PMT)

Photomultiplier tube (PMT) is a tube that functions to convert the spark of light into an electron beam. In this PMT tube, the light flicker generated from the scintillator will be received by the photocathode. When the photocathode is exposed to a light flicker, then from the surface of the photocathode it releases the electron. The electrons from the photo code are then focused on the stain. The resulting electron will be directed, with potential differences, towards the first station. The diode will emit several secondary electrons when subjected to electrons. Secondary electrons produced by the first will go to the second and multiply than to the third method and so on until finally collected at the anode. The output of the photomultiplier tube is an electric pulse which will then be processed.

1.3 Multi-Channel Analyser (MCA)

MCA is an electronic device used in gamma spectroscopy to observe the Energy of gamma-ray photons. The arrangement of equipment for observing gamma photon energy, as shown below:

![Figure 1. Spectroscopy Gamma Block Diagram](image)

Gamma spectrometers consist of detectors, pulse reinforcement systems, pulse processing systems, and data storage systems. The working principle of this tool is the ability of electrons to ionize and be excited when subjected to radiation so that electrons can move from the valence band to the conduction band which will produce electrical pulses [4].

The multi-channel analyzer (MCA) filters the output rays from the scintillation detector by using a large window so that it can make the entire spectrum of gamma-ray radiation in just one iteration. The scintillation detector generally converts the gamma photon energy produced by the radiation source into a voltage pulse with an altitude that is proportional to the amount of Energy. By an amplifier device, this voltage pulse is transformed into a semi-Gaussian with a flat peak without experiencing changes in height information. Thus this credit can be counted by the MCA. The same height pulses are counted on a container, with a channel number 1.3 Output.
scintillator detector. The detector output is the scintillator, as shown in Figure 2. The figure shows the Gamma-ray spectrum.

![Figure 2. The output of detector scintillation](image)

Component A-B-C-D describes when the radiation enters the crystal of the scintillator detector. At this time, there is an interaction between the atoms of the scintillator material according to the photoelectric effect, Compton scattering and pair production, which will result in flashes of light in the scintillator. If the Energy of the emitted radiation is absorbed entirely by electrons in the detector crystal, then this interaction is called the photoelectric effect which produces an energy peak (photopeak) in the gamma spectrum (A). The backscatter peak is caused by the photons that have been scattered out and are deflected back into the detector so that it is detected again (B). The boundary point between Compton and photoelectric interactions produces peak energy called the Compton edge (C). If a gamma photon interacts with a free electron or a weak one, for example, an electron in the outer shell of an atom, then some of the Energy of the photon will be absorbed by the electron and then scattered. This interaction is called Compton scattering (D).

### 1.4 Scintillation Detector Material

The scintillator used for spectroscopy is a single crystal alkali halide, Sodium Iodide (NaI). To increase the probability of photon emissions and reduce light absorption by crystals, a small amount of material called activator is added to NaI crystals. The most used activator is thallium, so the detector is called NaI (Tl). NaI Crystal (Tl) is one of the scintillator materials that is often used to detect gamma rays originating from low energy gamma sources. This is due to the presence of sodium elements which have a cross-section for the photoelectric effect with a large enough value for low energy gamma-ray radiation. This crystal is superior in light output and linearity, but the response time is low. Because NaI (Tl) crystals are hygroscopic, they are closed tightly in Aluminum (Al) containers coated with chromium (Cr). Between the crystal and the wall of the container Al is inserted into the reflector in the form of manganese oxide powder (MgO) or Aluminium trioxide (Al2O3), on one side is attached material from the glass, so that the light produced by the scintillator can reach the photocathode. Crystals are usually solid cylindrical with dimensions that are tailored to the needs and are glued to a double electron tube using a clear adhesive made of silicon oxide.
1.5 Characterization of $^{60}$Co Source

The $^{60}$Co isotope is produced by bombarding $^{59}$Co with neutrons in a nuclear reactor. The isotope produced at the nuclear reactor is used on Gamma Knife PerfexionTM aircraft. The $^{60}$Co isotope emits particles $\gamma$ with an energy of 1.17 MeV and 1.33 MeV [4], as shown in Figure 4.

![Figure 4. $^{60}$Co Decay Diagram](image)

2. Materials and methods

In this study, the initial thinking framework used the EGSnrc tutor3 standard model [2]. Figure 5 The ideal model geometry form of EGSnrc tutor3 program. The code is written in mortran language or called tutor3.morran EGSnrc.

![Figure 5. Model geometry tutor3. EGSnrc](image)
Figure 6 is a modification geometry model of the EGSnrc tutor3 program. In this simulation, we are going to use the tutor3 application to investigate transport parameters for a simple scenario: a pencil beam incident on a detector scintillation with the simulation setup as in the figure. The source surface distance (SSD) variation were 5, 5.5, 7.5, 8.5, and 9.5 cm. The number of history particle was used is 1 million photons. The effect of varied source distance to the detector was 5 to 5.5 cm, 5 to 7.5 cm, 5 to 8.5 cm, and 5 to 9.5 cm will be investigated.

The division of areas intended to determine the boundaries of simulation be performed. Regions 1 and regions 3 defined as a region of vacuum, and the area 2 is defined as the area scintillation material.

Simulation generally uses the EGSnrc GUI program by modifying some parameters in the tutor3.mortran file. Tutor3.mortran is one of the short tutorial programs on the EGSnrc (National Research Council of Canada Electron Gamma Software) software which is related to the response function of a detector. Variation in the distance is done by modifying the program. With this modification, the distance of the source of the detector can be varied according to the researchers' wishes. In this study, the range of detector distance was 5 cm, 5.5 cm, 7.5 cm, 8.5 cm, and 9.5 cm from the radiation source. Material is modeled with PEGS4, PEGS4 is a part program of EGSnrc which aims to collect information about a cross-section of material. This information is stored in the .pegs4.dat file. The file is used to run the tutor3.mortran program.

In tutor3 EGSnrc, MC simulation is carried out several steps, from steps 1 to 7 explicitly to produce AUSGAB output from tutor3.mortran. The output describes the interaction value of the photons in the detector crystal, which gives the output in the form of the intensity value of the incoming photon file that has been normalized at each specified energy bin. Simulation results are processed in the form of spectrum distribution. The research flowchart can be seen in Figure 7.
PEGS4 data is a material cross-section data program needed by EGSnrc for simulation. In the study, the system code was modified to produce the output response function of the crystalline detectors. There are several important parameters in determining data with PEGS4, namely determining the composition of the medium, medium type, density, and energy range. All input parameters that have been determined are inputted into the program.

In determining the composition of the medium, the important parameters that are determined are the elements of the medium and the percentage of the mass of each medium. Determining the name of the medium, provided in 24 characters without spaces, the range of Energy in MeV for the source of electron radiation and photons with AE energy is 0.512 MeV, AP is 0.01 MeV, EU and UP are 50 MeV respectively.

The output of tutor3.mortran is in the form of an energy spectrum. On the horizontal axis is Energy with units (MeV) and the vertical axis is a count.
Figure 8. Determination of output in an array gives the number of counts that are limited by certain Energy.

The output can be defined as an array that provides the number of counts but is limited by its Energy. If one particle is in the range of Energy or array, then the count increases.

3. Result and discussion

Material NaI (Tl) Scintillation was produced by PEGS4 data. In PEGS4, the data is determined by the composition of the material, type of material, density, and energy range. All input parameters that have been determined are entered into the program.

Simulation using tutor 3.morlan built based on seven steps in Monte Carlo. The simulation consists of steps 1 to 7 explosively with a photon radiation source that is, 1). Selection of Energy, direction, and starting position, 2). Selection of the distance for the first interaction, 3). Selection of interaction type, 4). Selection of direction, Energy, and position of new particles, 5). The scattered photon transport, 6). Secondary electron transport, and 7). Scoring Energy absorbed. In our study, We changed in steps 1, 2, 4, 6, and 7.

In step 1 until 2, a scintillation detector material is defined by giving the name of the material. The Energy of Cut Off for electrons and photons is also inputted in this section.

```fortran
CHARACTER*4 MEDARR(24);
DATA MEDARR /$'NAI(TI)760ICRU',10**$ 'place medium name in an array''
" $S is a MORTAN macro to expand strings"
" Initialize the EGSnrc system "
call egs_init;
DO I=1,2,4(MEDIA(I,1)-MEDARR(I);"this is to avoid a data statement for"
" a variable in COMMON"
"NMED and DUNIT default to 1, i.e. one medium and we work in cm"
/MED(1),MED(3)=0;MED(2)=1;"vacuum in regions 1 and 3, TA in region 2"
%E "tutor3.morlan"
ECUT(2)=0.7;" terminate electron histories at 0.7 MeV in the detector"
PCUT(2)=0.1;" terminate photon histories at 0.1 MeV in the detector"
" only needed for region 2 since no transport elsewhere"
" ECUT is total energy = 0.189 MeV kinetic energy"
```

Figure 9. Modification code tutor3.morlan in step 1 – 2.
In step 4, the scintillation detector size is defined by 5 cm [4]. In step 5 the desired width of Energy is modified. The selected energy bin (EBIN) of 140 with B WIDTH is 0.2 for the maximum energy spectrum at an output of 1.40 MeV. In step 6 the important part is to vary the $^{60}$Co source distance to the scintillation detector. The distance variations carried out in this study were 5 cm, 5.5 cm, 7.5 cm, 8.5 cm, and 9.5 cm. In step 7 a history particle is used. This time the simulation used $1.2 \times 10^9$ particles.

Figure 10. Modification code tutor3.mortran in step 4 – 7

Results of spectrum distribution seen in two areas. The photopeak area and the Compton edge peak area is a decrease in the count area.
Figure 11. Spectral distribution in (a) photopeak area, and (b) Compton peak area

In the photopeak area, there was a decrease in counts of 2.28%, 2.72%, 12.18%, and 15.83, respectively, as Table 1.

| Distance | % Change |
|----------|----------|
| 5 – 5.5 cm | 2.28 % |
| 5 – 7.5 cm | 2.72 % |
| 5 – 8.5 cm | 12.18 % |
| 5 – 9.5 cm | 15.83 % |

The farther the distance of the source to the detector, the less the value of the count produced in the photopeak area. Different conditions occurred in the Compton peak area, and there was an increase in counts of 5.11%, 27.15%, 35.96%, and 44.58, respectively as Table 2.

| Distance | % Change |
|----------|----------|
| 5 – 5.5 cm | 5.11 % |
| 5 – 7.5 cm | 27.15 % |
| 5 – 8.5 cm | 35.96 % |
| 5 – 9.5 cm | 44.58 % |
The farther the distance of the source to the detector, increasing the value of the count produced in the Compton area. Validate the results obtained in each of these areas, and regression coefficient testing was carried out with the following results:

**Figure 12. Regression coefficient in Photopeak area**

Based on Figure 12 can be seen that the effect of distance on the count value follows the inverse square law with the R-value = 0.9963 for the photopeak area.

**Figure 13. Regression confession in the Compton area**

Based on Figure 13 can be seen that the effect of distance on the count value follows the inverse square law with the R-value = 0.9955 for the Compton peak area.
4. Conclusion

Variation of distance the source ($^{60}$Co) to the NaI (Tl) scintillation detector results is the opposite result in the photopeak area and the Compton peak area. The greater the distance detector from the source, the smaller peaks in the Photopeak area and the higher peaks in the Compton peak area.

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