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Evaluation of Virtual Point Detector for High Purity Germanium (Hpge) Detector, using Monte Carlo Simulations, and Artificial -Neural Networks

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ABSTRACT

The virtual point detector concept is useful in gamma-ray spectroscopy. In this study, the virtual point detector, h_0, was obtained for High Purity Germanium (HPGe) detectors of different sizes using MCNP5 Monte Carlo simulations. The HPGe detectors with different radii (rd), and height (hd), having aluminum, or Carbon windows, were simulated. A point photon source emitting several gammas with specific energies was defined at a distance x of the detectors. The pulse height distribution was scored using F8 tally. Finally, the artificial neural network was used for predicting the h_0 values for every value of hd, rd, and x. Because of the high simulation duration of MCNP code, a trained ANN is used to predict the value of h0 for each detector size. The results indicate that the Artificial Neural Network (ANN) can predict the virtual point detector good accuracy.

Keywords: *virtual point detector, efficiency, natural radionuclides, HPGe, artificial neural network*

INTRODUCTION

The efficiency of HPGe spectrometers is dependent on distance between the source, and the detector. As the photons undergo interactions in the whole detector, this dependency doesn't follow the inverse square law. However, Notea introduced the concept of virtual point detector that suggests a point inside an HPGe detector[1], in which we may suppose that all interactions have occurred. This concept is important, because it allows approximations of inverse square law, and the efficiency calculations are simplified, what would otherwise need very complicated mathematical calculations. This point is called the virtual point detector whose distance from the detector entrance is denoted as h0 [1] [2] [3][4]. The virtual point detector is only a mathematical simplification and, is not a physical concept. For planar and semi-planar detectors, it may lie outside the detector [5][6]. The idea of the virtual point detector can also be used for radioactive volume samples, by an integration over the whole sample[2]. Alfassi *et al.* expanded this concept for disk sources[7].

This study aims to determine the virtual point detector for the HPGe detectors, with different sizes, using MCNP5 Monte Carlo simulations, and artificial neural network.

MATERIALS AND METHODS

A simplified HPGe detector was simulated using MCNP5 Monte Carlo code. MCNP has been proved to be a very effective method in simulation of different radiation detectors, for radiation dosimetry[8][9][10], shielding[11][12], obtaining the accurate detector efficiency[13][14][15], and determining the virtual point detector[6][16][17]. The simulation geometry is shown in Figure 1. The simulations were performed for variable source to detector distances, x, radius, rd, and hight, hd. A 0.1 cm aluminum layer was simulated as the entrance window. A 0.5 cm vacuum layer was also defined after the aluminium window.

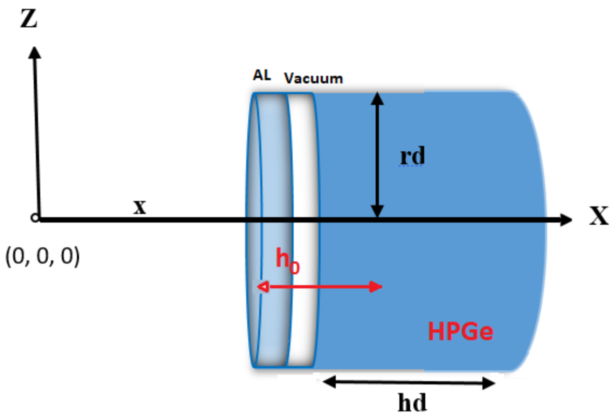

Figure 1: The Simplified Simulation Geometry, Hpge, A Vacuum Layer, and Al Window (source by author)

The source was simulated at point (0,0,0) at distance x from the detector. The simulations were performed for h_d, and r_d=1, 3, 5, 7, 9, 11, and 13cm, and x=1, 3, 5, 10, 15, 20, 25, and 30cm. The point source was considered as a photon source with energies of 0.186, 0.308, 0.468, 0.662, 0.835, 1.332 and 1.836 MeV, respectively with equal probabilities.

5×10^7 particle histories were considered in the simulations, to reduce the relative error to less than 0.05. In order to reduce the variance of simulations, the source was considered as a cone whose vertex is at the source, and its base is on the detector window[18]. Tally type F8 was used for gamma spectroscopy. 254 energy bins were defined for scoring the tally, between 0 and 2.56 MeV.Next, a Gaussian Energy Broadening (GEB) was used to consider the FWHM of the HPGe in our calculations. Virtual detector points for different detector geometries were obtained by simulating count rates at different source to detector distances along the x-axis. The validity of the virtual point-detector model can be proven by the following proportionalities:

$$Y = \left[\sqrt{\frac{C(x_0)}{C(x)}} - 1\right] \qquad (1)$$

$$X = [x - x_0] \qquad (2)$$

C(x0) is the count rate at point x0 near the detector surface (in this work: x0= 0.1 cm)

C(x) is the count rate at variable detector cap to source distances x.

When plotting Y vs X, The virtual detector point distance h0 can be obtained from the slope of the straight line forced through the origin.

$$\sqrt{\frac{C(x_0)}{C(x)}} - 1 = \frac{x - x_0}{h_0 + x_0} \qquad (3)$$

RESULTS AND DISCUSSIONS

Virtual point detector vs detector dimension, SDD, and energy

Figure 2 shows the spectrum obtained from the Monte Carlo calculation. The effect of the detector dimensions on the value of h_0, can be seen in Figures 3, and 4. Figure 3, shows the virtual point detector (HPGe-Al window), h_0, versus detector height, h_d, for x=5cm, and different detector radius, rd, and energies, for Al window.

Figure 4, shows these values for x=30cm. Figure 4 also shows the dependence of virtual point detector on the source to detector distance for several cases. The effect of the source to detector distance on h_0 is shown in Figure 5.

The simulations were performed for HPGe with carbon window. Figure 6 shows the h_0 values for carbon window.

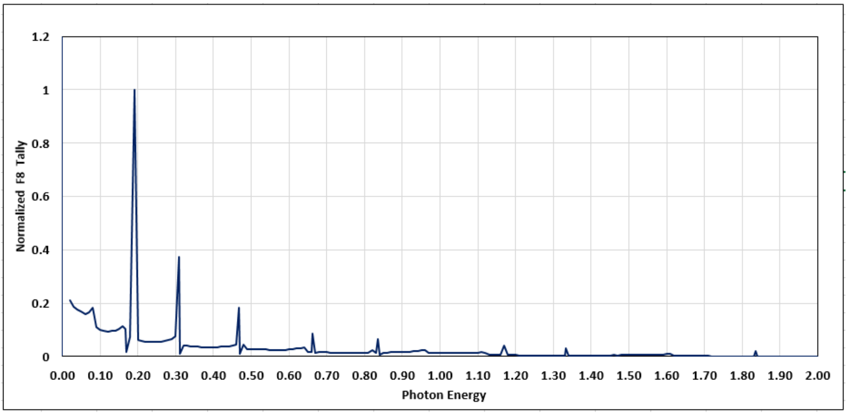

Figure 2: The Spectrum Obtained By F8 Tally

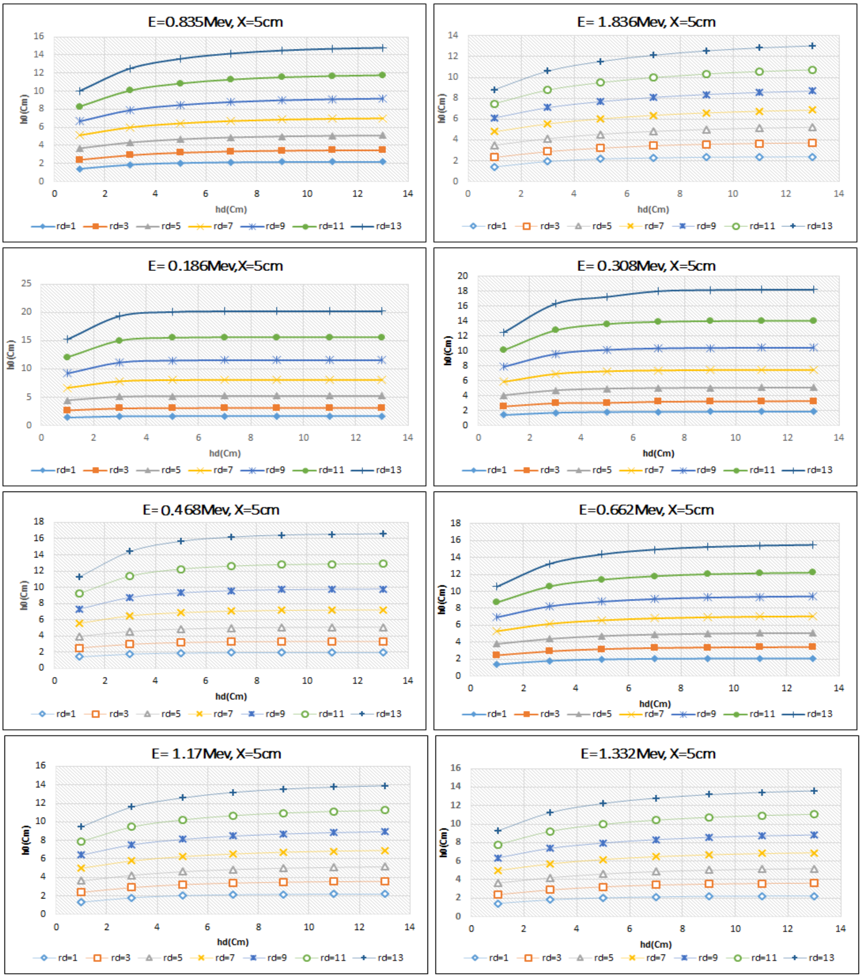

Figure 3: Virtual Detector Point Distances h0 versus Detector Diameter rd at Constant hd Value Points are from MCNP Simulations for Different Photon Energies for x=5 cm, for AL Window

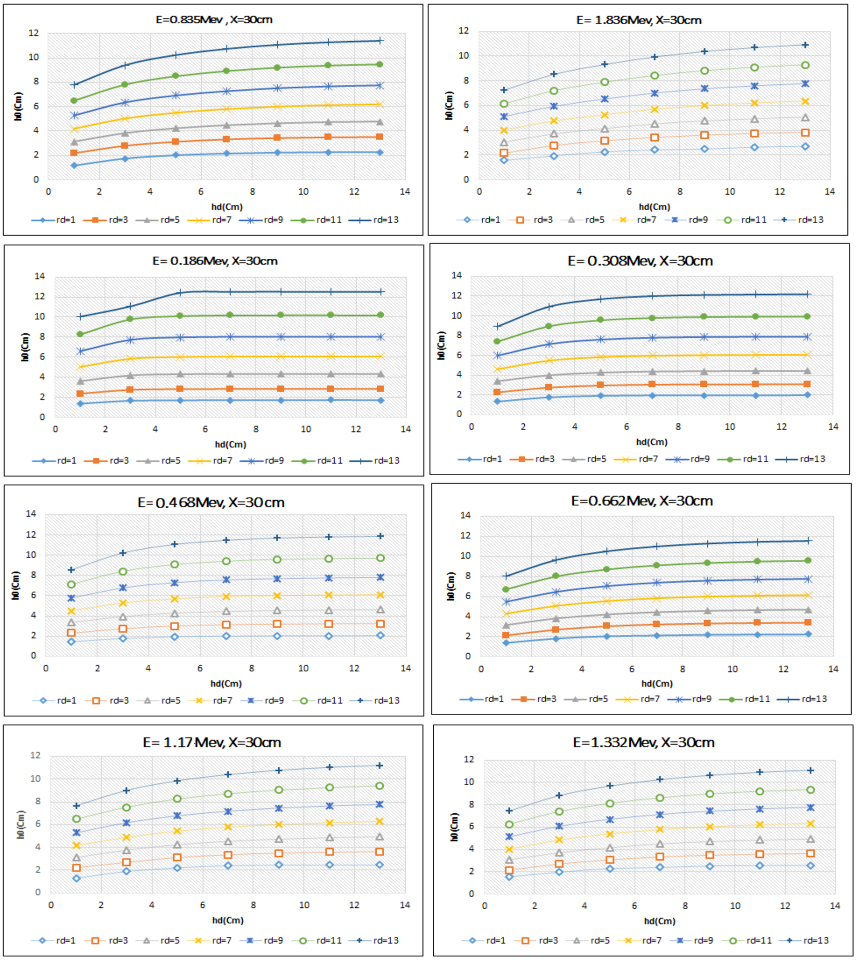

Figure 4: Virtual Detector Point Distances h_0 versus Detector Diameter r_d at Constant h_d Value Points are from MCNP Simulations for Different Photon Energies for x=30cm, for AL Window

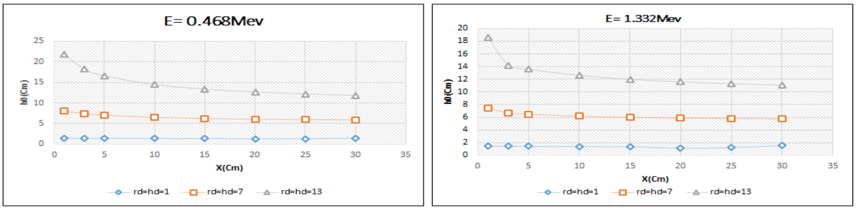

Figure 5: The Effect of Source to Detector Distance on h0, for AL Window

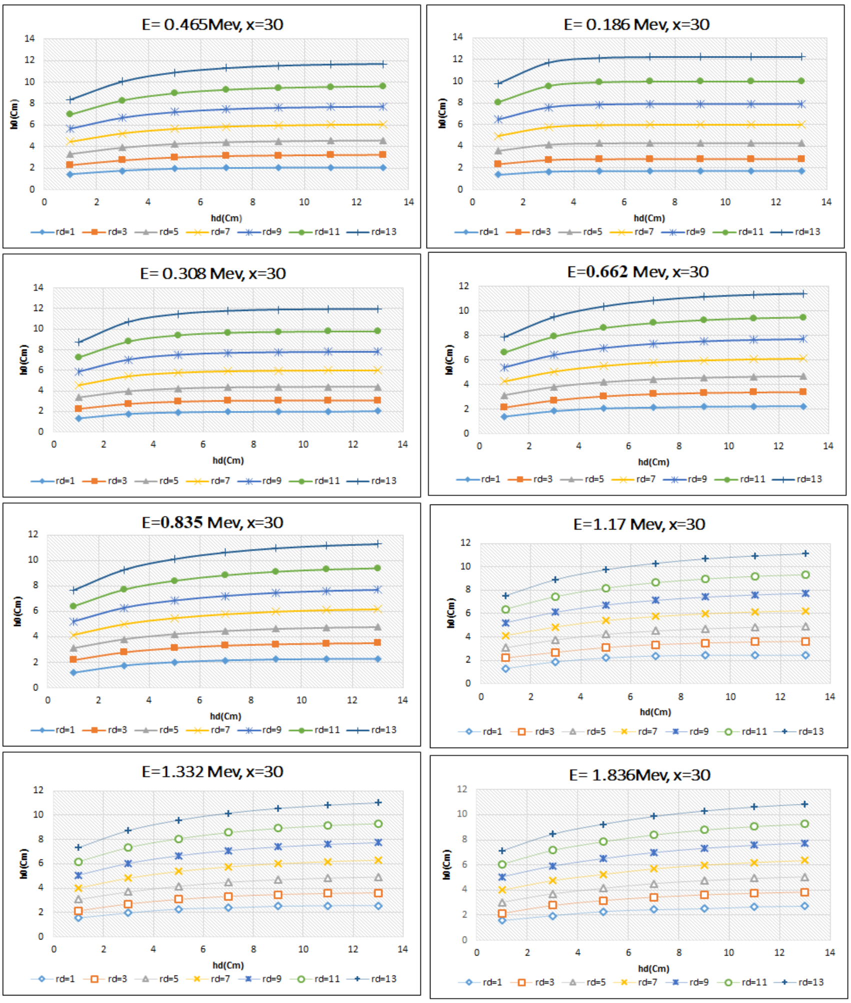

Figure 6: Virtual Detector Point Distances h0 versus Detector Diameter rd at Constant hd Value Points are from MCNP Simulations for Different Photon Energies for x=30cm, for Carbon Window

Prediction of h0 with artificial neural network

An ANN was used for estimation of h_0 for other detector sizes, SSD values, and Energies. A matrix containing different values of hd, rd, energy, and x was defined for the number of 6273 simulations. The number of hidden neurons was chosen to be 5, as we got the best results. The architecture of the neural network is shown in Figure 6.

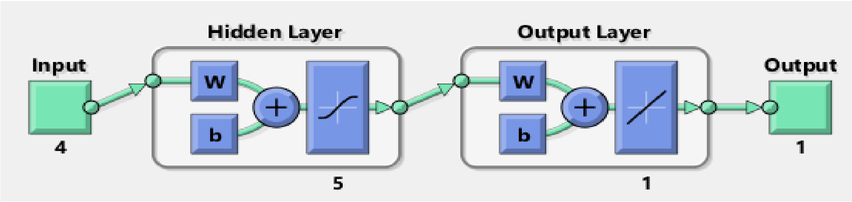

Figure 7: The Architecture of the Neural Network in MATLAB [19]

80% of the data were used for training the network, 10% for testing, and 10% for training. The Levenberg-Marquardt training algorithm was used for training the network, as it is the fastest backpropagation algorithm in the MATLAB toolbox. Linear activation function was used for the ANN.

Table 1 compares the results of MC simulations with the prediction of artificial neural networks. We used the MCNP simulation results for training the network, and the MCNP simulation results were used as the reference. The results indicate that the ANN can predict the h0 values with the percentage relative difference between the actual value, (MCNP result), and the estimated one, (ANN result) was less than 5%. The ANN can predict faster than MCNP Monte Carlo code, with high accuracy.

Table 1: Comparison of Artificial Neural Networks Prediction with Results of MC Simulations for Aluminium, and Carbon Window

Radius (rd) cm	Height (hd) cm	SSD (x) cm	Energy Mev	Window	h0 MC simulations	h0 ANN predictions
1	5	1	0.186	Al	1.64	1.63
7	12	1	0.186	Al	10.40	10.45
9	10	25	0.662	Al	7.82	8
5	6	10	1.332	C	4.6	4.5

CONCLUSION

6273 simulations were performed to estimate the virtual point detector for HPGe detectors of different sizes. Eight different photon energies were considered in the simulations. According to the results, in some cases, the point h0 is found to be outside the detector volume. This fact can be seen that for those detectors having large radii and small heights. According to the results, ANN can be effectively used in prediction of the virtual detector point. It should be stated that the ANN can also be optimised by varying useful parameters such as learning rate.

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