[[1]](#footnote-1)

Automated Parametric Optimization of a High-Purity Germanium Monte Carlo Neutral-Particle Model (December 2017)

Bryan V. Egner, *Student, AFIT*, Robert S. Torzilli, *Student, AFIT*

*Abstract*—One Hundred fiftey – 250 words

*Index Terms*—Enter key words or phrases in alphabetical order, separated by commas. For a list of suggested keywords, send a blank e-mail to [keywords@ieee.org](mailto:keywords@ieee.org) or visit <http://www.ieee.org/organizations/pubs/ani_prod/keywrd98.txt>

# INTRODUCTION

G

amma-ray spectroscopy using high-purity germanium (HPGe) detectors is a leading method for obtaining high-energy resolution spectra in both the laboratory setting and in the field. These detectors have the ability to obtain energy resolutions as low as 0.15 keV for the Full-Width-Half-Maximum (FWHM), at incident photons around 5.9 keV. [1] The tradeoff for such high energy resolution, is an overall lower detection efficiency compared to other types of nuclear instrumentals, such as sodium iodide NaI scinitllators. The advancement of radiation transport codes, such as Monte Carlo Neutral-Particle (MCNP), allows researchers to accurately model the detection response of HPGe detectors at various geometries, source energies, and environments. Radiation transport modeling provides insight to potential anomalies that could occur during an experiment, and enables the user to intelligently modify experiments which could improve results, conserve resources, and ensure safety requirements are followed. Unfortunately, creating a detector MCNP model that accurately represents reality can be difficult and time consuming, and so by applying a systematic or computational approach the process can be streamlined. Rather than manually performing trial-and-error adjustments to match experimental data, the development of an automated parametric optimization code will simplify the enhancement of a rudimentary HPGe detector model. Ideally, an optimized HPGe MCNP model should accurately predict the detection efficiency curves at various source positions, which can then be applied to developing an adjoint flux model representing the detection efficiency over all space.

# Problem Description

The development of an MCNP model that accurately resembles a detectors experimental response is not an elementary task. Factors to consider when modeling are: the type and position of the radiation source, the properties, both geometrical and compositional of the detector being modeled, and the characteristics of primary and secondary incident radiation. Published literature has stated relative differences between the experimental and Monte Carlo simulated full-energy peak absolute efficiencies for HPGe detectors have reached as low as 0.2%. [2] There has also been studies showing discrepancies between the manufacturer-provided detector specifications of internal components compared to measured values, such as the crystal length and dead layers. [3]

Experimental measurements of gamma-ray emissions using a standard Canberra p-type HPGe detector were provided by Lieutenant Colonel Buckley O’Day using a multi-nuclide source. The multi-nuclide source covered photon energies ranging from 0.06 to 1.836 MeV, which allowed for a full representation of the absolute efficiency curve. The numerical values listed for the energies in Table 1 follow the rounding format listed on the source specifications sheet provided by Eckert & Ziegler Isotope Products for consistency, and the documentation also states the source uncertainty to be 3.1% for each energy.

|  |  |  |  |
| --- | --- | --- | --- |
| TABLE I  Multi-nuclide Source Information | | | |
| Gamma-Ray Energy [keV] | Nuclide | Activity [µCi] | Gammas per Second |
| 60 | Am-241 | 0.02941 | 391.7 |
| 88 | Cd-109 | 0.2707 | 363.6 |
| 122 | Co-57 | 0.01019 | 322.7 |
| 159 | Te-123 | 0.01403 | 436.1 |
| 320 | Cr-51 | 0.3389 | 1236 |
| 392 | Sn-113 | 0.05109 | 1227 |
| 514 | Sr-85 | 0.06171 | 2247 |
| 662 | Cs-137 | 0.04325 | 1362 |
| 898 | Y-88 | 0.09633 | 3347 |
| 1173 | Co-60 | 0.05101 | 1885 |
| 1333 | Co-60 | 0.05101 | 1887 |
| 1836 | Y-88 | 0.09622 | 3539 |

A labeled diagram of the various source positions with respect to the HPGe detector are shown in Figure 2. At each position, a 24-hour count was performed to minimize uncertainty. For positon 1, the source was placed centered on the Al casing, position 2 was resting on the front face and flush with the edge of the casing, position 3 was centered 7 cm above the front face, position 4 was placed 3 cm down the side of the casing, and positon 5 was offset 13 cm above the detector.

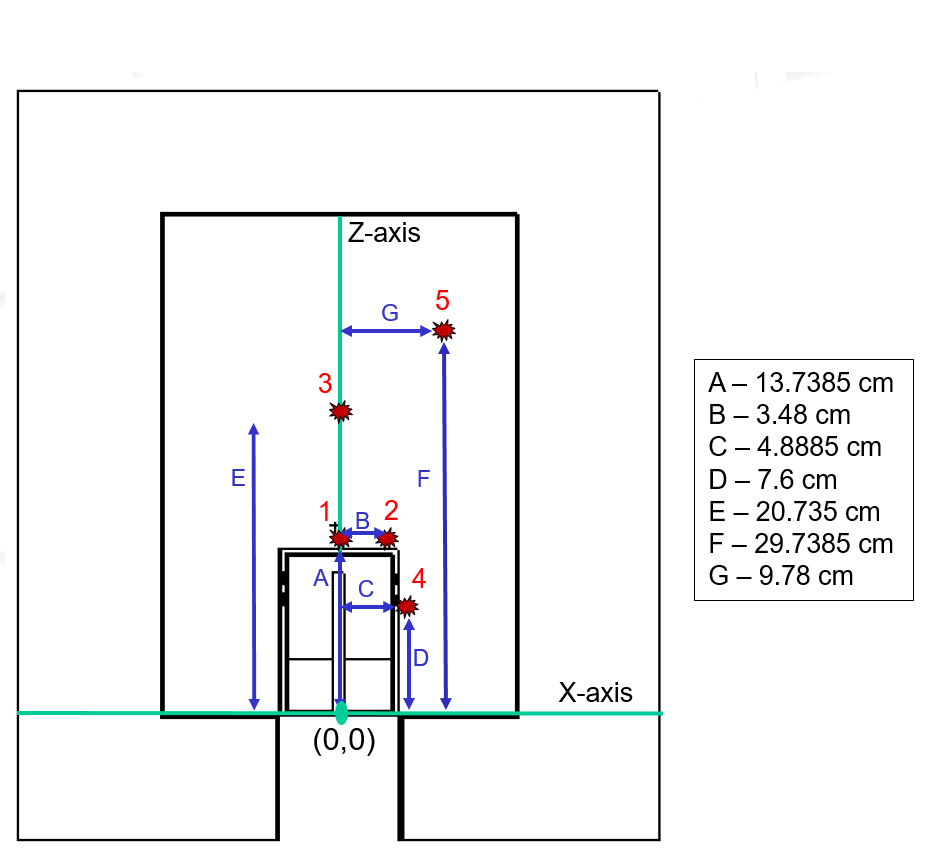


Fig. 1. Experimental setup diagram, displaying each source position on a Cartesian coordinate system, where the origin is centered at the base of the Al casing of the detector

A plot of the spectra, and the calculated absolute efficiencies as a function energy were also provided by Lt Col O’day, for comparison with the simulated results. The absolute efficiency was calculated using equation 1.

Equation 1

Where Nc is the total number of counts under the full-energy peak, Ag is the amount of gammas emitted per second which is listed in column 4 of Table 1, multiplied by the live time, tl. And the source decay is accounted for by multiplying the denominator by the decay exponential where t1/2 is the half-life, and td is the age of the source.

# Description of Work

First, an HPGe detector model was created using MCNP, and then an optimization code was produced in Python. After the model was optimized: Efficiency curves were plotted for a quantitative analysis, and then ADVANTG weight windows were implemented to generate the adjoint flux response for a qualitative representation of the results.

## HPGe MCNP Model

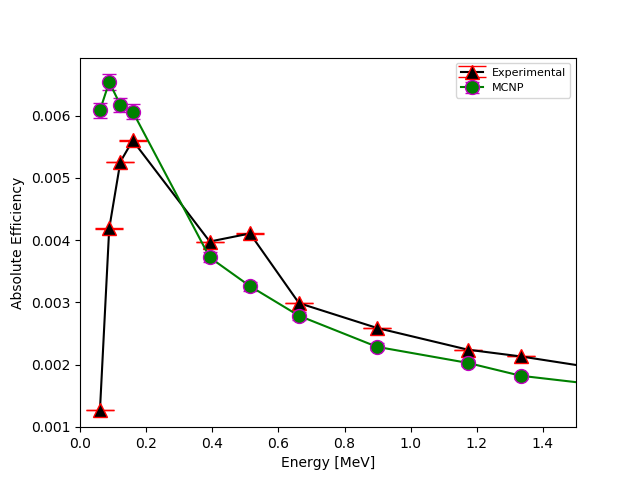
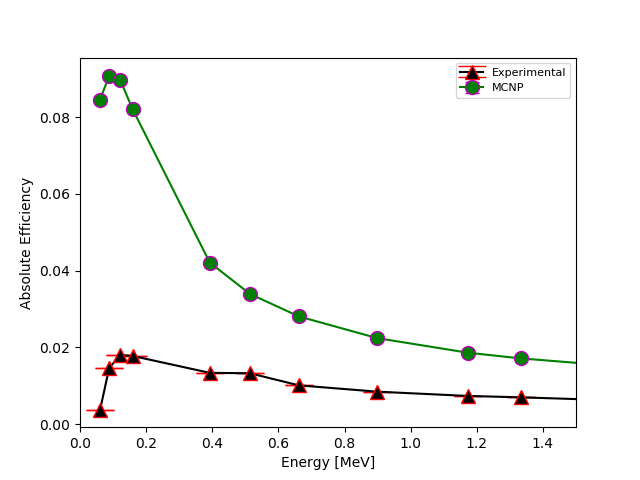
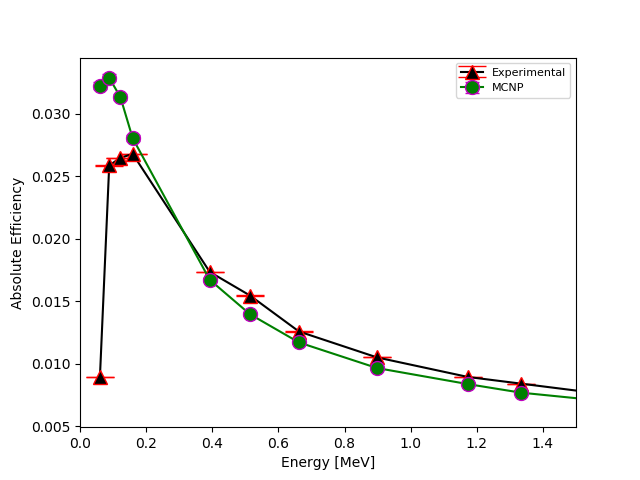
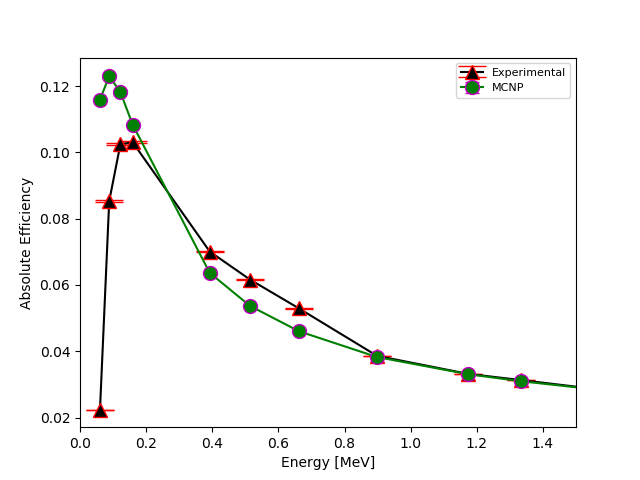
Model development

## Automated Parametric Optimization Code

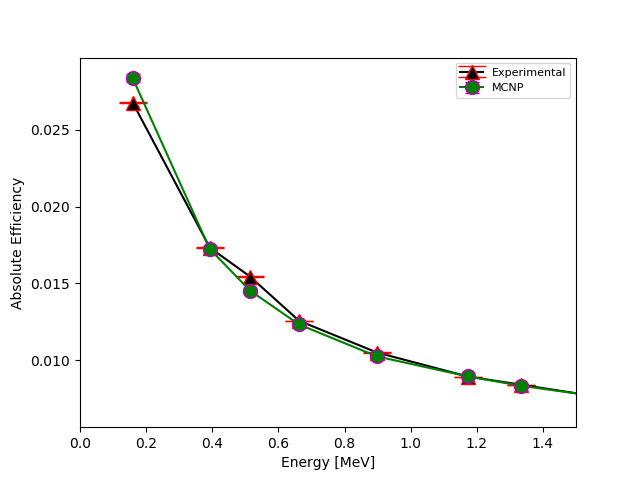
Describe how/what/all details about the code and what it does. Along with Chi-square, etc. ( Try and match my equation 1 format, but I can always edit it, just use the equation editor to start)

# Results

What are the optimal paraemeters at each source position?ficiency plots/total relative difrence



|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| TABLE 2  Optimized Detector Parameters | | | | | | |
| Parameter | Initial Value | Position | | | | |
| 1 | 2 | 3 | 4 | 5 |
| Outer Top Deadlayer [cm] | 0.13 | 0.7389 | 0.7389 | 0.7389 | 0.7389 | 0.7389 |
| Outer Sides Deadlayer [cm] | 0.13 | 0.23 | 0.23 | 0.23 | 1.35 | 0.23 |
| Ge Crystal Length [cm] | 8.32 | 7.6627 | 7.4749 | 7.4749 | 7.4749 | 7.4749 |
| Kapton Window [cm] | 0.01016 | 0.1101 | 0.1101 | 0.1101 | 0.0576 | 0.1101 |
| Inner Top Coaxial Deadlayer [cm] | 0.00003 | 0.0001 | 6E-05 | 6E-05 | 0.0001 | 6E-05 |
| Inner Sides Coaxial Deadlayer [cm] | 0.00003 | 2E-05 | 6E-05 | 7E-05 | 0.001 | 7E-05 |
| Top Al Casing Thickness [cm] | 0.15 | 0.25 | 0.25 | 0.25 | 0.05 | 0.25 |
| Sides Al Casing Thickness [cm] | 0.15 | 0.05 | 0.05 | 0.05 | 0.27 | 0.25 |
| Ge Crystal Density [g/cm3] | 5.32 | 5.32 | 5.32 | 5.35 | 5.32 | 5.3425 |



# Conclusion

## What do your findings mean? How does that relate to the goal you laid out in the introduction?

Appendix

Appendixes, if needed, appear before the acknowledgment.

Acknowledgment

The preferred spelling of the word “acknowledgment” in American English is without an “e” after the “g.” Use the singular heading even if you have many acknowledgments. Avoid expressions such as “One of us (S.B.A.) would like to thank ... .” Instead, write “F. A. Author thanks ... .” In most cases, sponsor and financial support acknowledgments are placed in the unnumbered footnote on the first page, not here.

References

*Basic format for books:*

J. K. Author, “Title of chapter in the book,” in *Title of His Published Book, x*th ed. City of Publisher, (only U.S. State), Country: Abbrev. of Publisher, year, ch. *x*, sec. *x*, pp. *xxx–xxx.*

*Examples:*

1. G. O. Young, “Synthetic structure of industrial plastics,” in *Plastics,* 2nd ed., vol. 3, J. Peters, Ed. New York, NY, USA: McGraw-Hill, 1964, pp. 15–64.
2. W.-K. Chen, *Linear Networks and Systems.* Belmont, CA, USA: Wadsworth, 1993, pp. 123–135.

1. B. V. Egner is with the Engineering Physics Department at the Air Force Institute of Technology, Wright Patterson AFB, OH 45431 (e-mail: [bryan.egner@afit.edu](mailto:bryan.egner@afit.edu), phone: (717)736-3846).

   R.Torzilli is with the Engineering Physics Department at the Air Force Institute of Technology, Wright Patterson AFB, OH 45431 (e-mail: [robert.torzilli@afit.edu](mailto:robert.torzilli@afit.edu), phone: (717)736-3846). [↑](#footnote-ref-1)