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Title: Validation Study of the Spacecraft Background Activation using RHESSI Data

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Validation Study of the Spacecraft Background Activation using RHESSI Data

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1 Introduction

This document serves as a brief writeup of the work done to validate CINDER2008 and the Activation Analysis Tools in the Activation in Accelerator Radiation Environments (AARE) distribution that are used to calculate the activation of spacecraft material while in orbit [1–3]. The validation study involves replicating the decay gamma spectrum as observed onboard the RHESSI spacecraft in the high-purity germanium (HPGe) detectors after crossing the South Atlantic Anomaly (SAA) [4]. The tools involved are a suite of Python scripts, the transmutation code CINDER2008 accompanied with a suite of scripts distributed with AARE,MCNPX, and MCNP6.2 [2,5–7]. Figure 1 shows the gamma ray spectrum this study replicates as the spectrum designated "Difference".

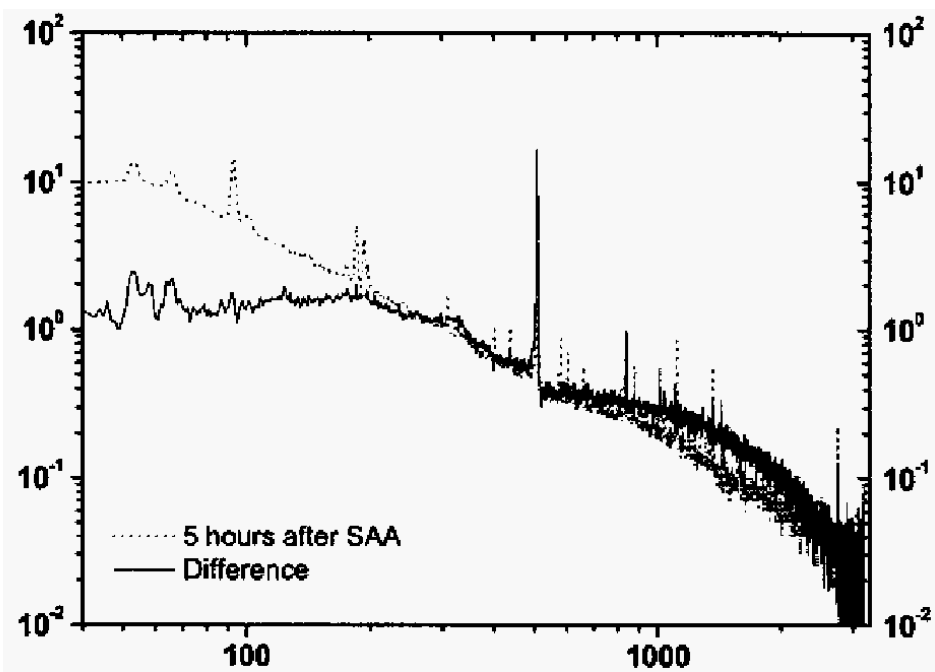

Figure 1: HPGe spectrum of gamma ray background measured after RHESSI crossed the SAA [4]

2 Methods

The method for simulating the gamma spectrum shown in Figure 1 is to start out simulating the cosmic-ray protons incident upon the detector and shield in order to gather the neutron flux in the detector volume. This initial step is detailed in Section 2.1. The next step is to use the cosmic-ray induced neutron flux within the detector and shield volume as input to the transmutation code, CINDER2008. CINDER2008 then transmutes the material by considering the decay nuclide characteristics and neutron flux, and calculates the decay gammas emission rate from the transmuted material. The details of this calculation is in Section 2.2. The Gamma Source script (distributed along with CINDER2008) reads in the decay gamma emission rates as a function of energy and cell and produces a SDEF card for another MCNP6.2 run. The MCNP6.2 run then transports the gammas emitted from the detector and shield volumes to tally the HPGe detector spectrum that is the simulation of the measured spectrum shown in Figure 1. The details of the final MCNP6.2 simulation are given in Section 2.3. An overview of the calculations and weighting schemes is given if Figure 2.

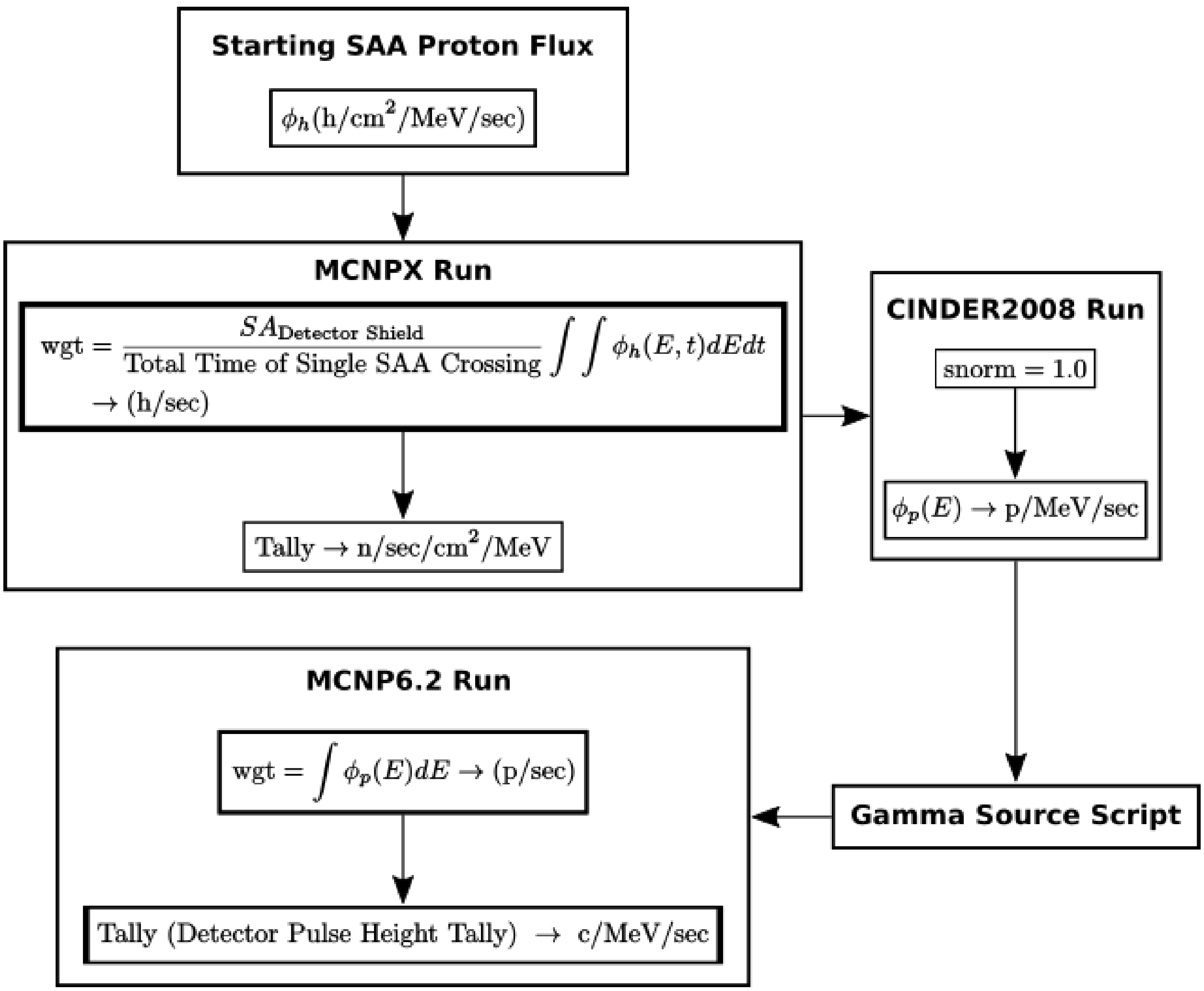

Figure 2: Overview of the calculation, normalization, and weighting process.

2.1 Incident Proton MCNP Model

2.1.1 Geometry

The RHESSI satellite is fitted with nine of HPGe detectors (7.1 cm diameter and 8.5 cm height) covered by a graded-z shield with a total thickness of 2 mm [4,8]. The HpGe detectors onboard the RHESSI spacecraft are of coaxial design, but the HPGe detector modeled in MCNPX are modeled as a solid block and is shown in Figures 3 & 4 with the scales in units of cm. The natural isotopic composition of germanium is used as the material of the HPGe and the shield consists of: from inside out 0.5 mm of stainless steel, 1.0 mm of tin, and 0.5 mm of tantalum.

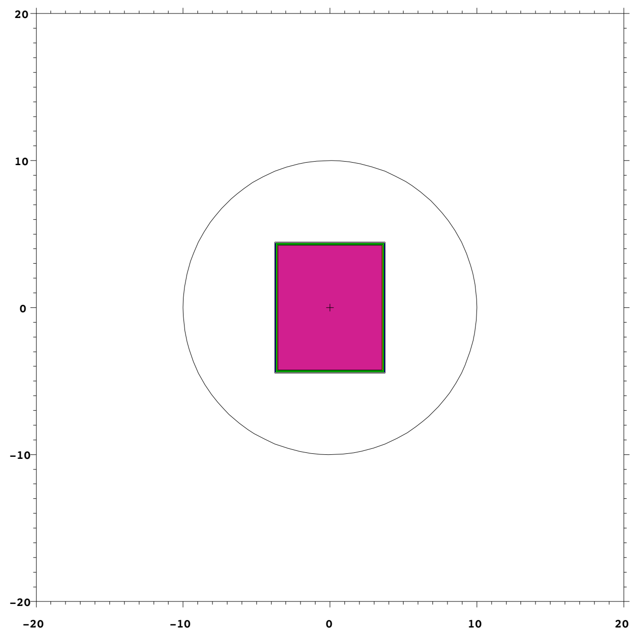

Figure 3: Y-Z cross section of the HPGe detector with the graded-z shield.

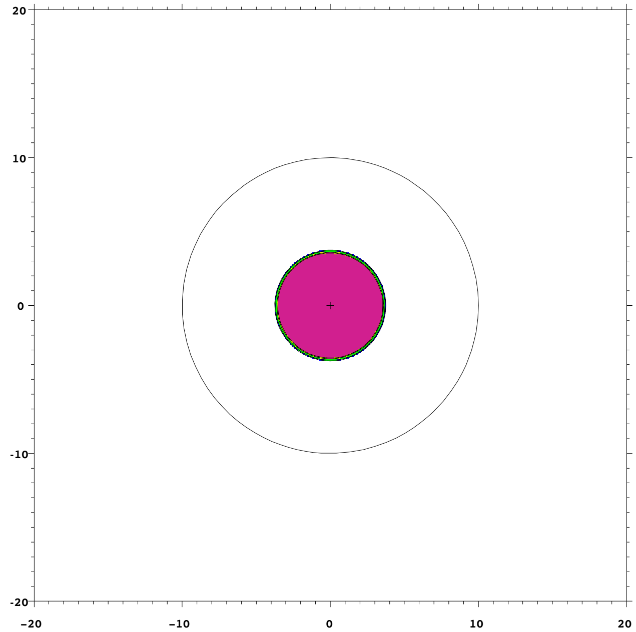

Figure 4: X-Y cross section of the HPGe detector with the graded-z shield.

2.1.2 Source

The SAA proton source used in this study is a result of a simulation of the RHESSI spacecraft with the A-9 model for the exact day the Figure 1 was produced at the same altitude latitude, and longitude. Figure 5 shows the SAA proton spectrum as a function of energy and row number. Each row in the plotted data represents the time integral of 10 seconds.

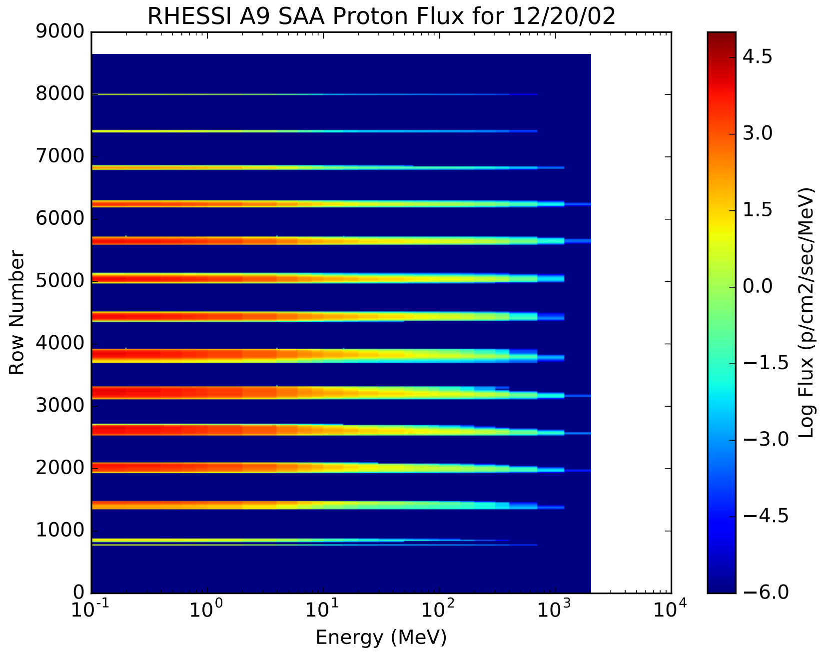

Figure 5: SAA differential proton flux generated by the A-9 model

Figure 6 shows the integral proton flux as a function of row number as calculated by Equation 1 where $\Phi(E,t)$ is the SAA differential proton flux in units of (h/sec/cm^2/MeV) and the resulting integral proton flux, $\phi_h(t)$, is in units of (h/sec/cm^2).

$$\phi_h(t) = \int \Phi_h(E,t)dE \tag{1}$$

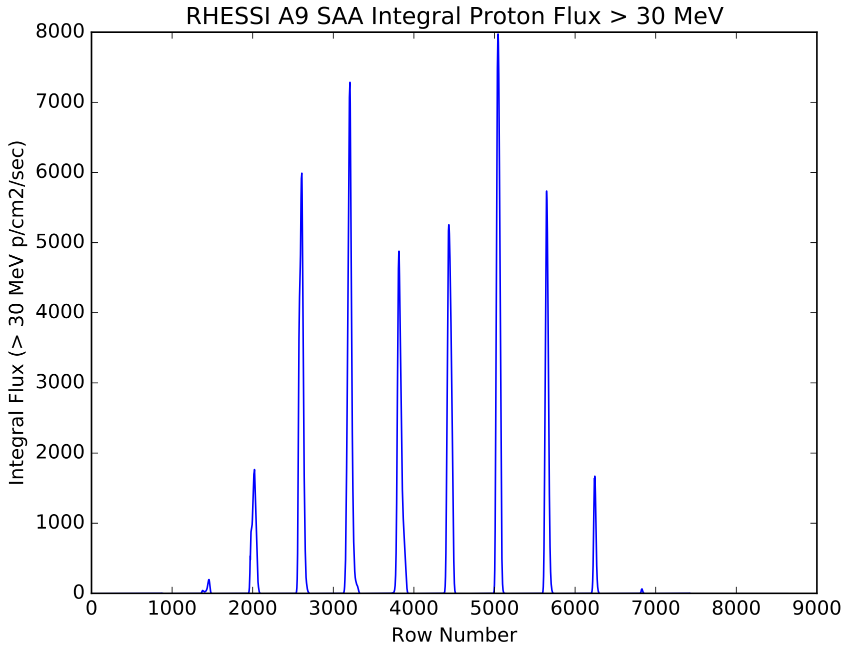

Figure 6: SAA integral proton flux generated by the A-9 model

The source spectrum shown in Figure 7 is representative of the average incident differential proton flux, $\Phi_h(E,t)$, while the RHESSI spacecraft traverses the SAA. The exact time of day associated with line number 3180 in Figure 7 is 08:47:30 GMT on December 20, 2002.

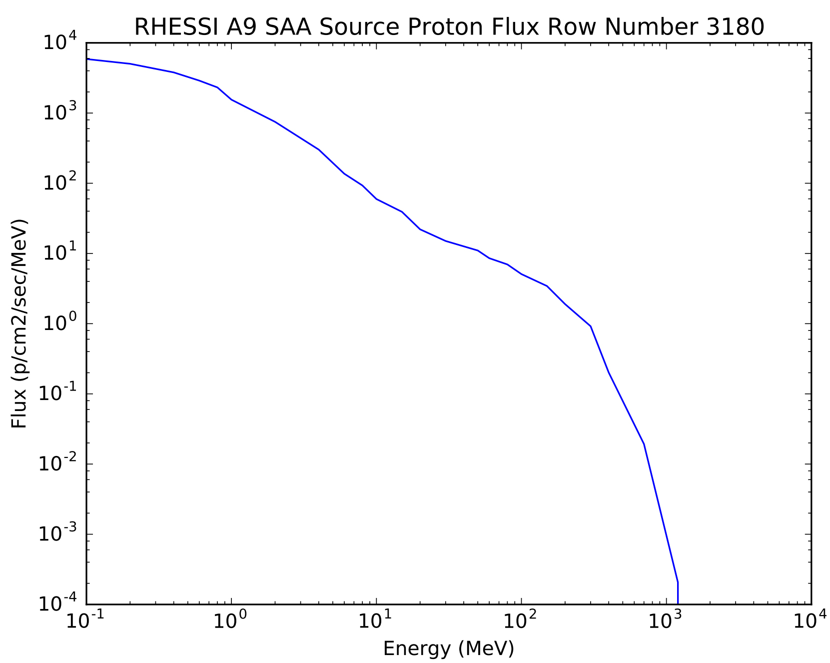

Figure 7: Source SAA proton flux

The source SAA proton flux shown in Figure 7 is implemented as a source directed inward on the surface of the detector shield. In order to include the source SAA proton flux into the initial MCNP simulation, the wgt was calculated using Equation 2 where $SA_{\text{Detector Shield}}$ is the surface area of the detector shield and $\phi_h(E,t)$ is the energy and time dependent proton flux. The weight is the time averaged integral proton flux over the entire time of SAA crossing in units of (h/sec). This weight appropriately scales the tallied neutron flux in the HPGe detector to match the neutron fluxes in the HPGe onboard the RHESSI spacecraft.

$$\text{wgt} = \frac{SA_{\text{Detector Shield}}}{\text{Total Time of Single SAA Crossing}} \int\int \phi_h(E,t)dEdt \tag{2}$$

2.1.3 Physics

In order to simulate every avenue of neutron production, neutrons, photons, alpha particles, protons, pions, deuterons, tritons, and helions are included and the upper energy threshold is set to 2 GeV. The neutron transition energy from cross-section table based physics to physics model based physics is set to 20 MeV. Physics models were used for protons above 1 MeV and cross-sections (where available) were used for protons below 1 MeV.

2.1.4 Tallies

The neutron flux was tallied in both the detector and the detector shield in the same energy bin structure as the 321-group flat-spectrum weighted cross section set within CINDER2008. The tally output is in units of n/sec/cm^2/MeV.

2.2 Material Transmutation

The Activation Script (distributed with CINDER2008) is a Perl script that reads in the output file, and HISTP file from the previous MCNPX run and constructs the input files for CINDER2008 [9]. CINDER2008 takes the neutron flux in units of n/sec/cm^2/MeV and transmutes the material designated by the input file to produce a number of tables detailing the transmuted material's isotopic composition and the decay gammas for specified timesteps. The decay gamma emission rates are printed as a function of energy in units of p/MeV/sec and their emission locations are assumed to be uniformly distributed out of the parent cell. The Gamma Script (distributed with CINDER2008) takes these decay gamma emission rates along with the cell information from the MCNPX run and creates an source definition card for a following MCNP6.2 run.

For this particular simulation of the RHESSI data, the timesteps used in the CINDER2008 are 35 minutes of passing through the SAA followed by 5 min of no SAA.

2.3 Decay Gamma Transport

In order to reproduce the gamma spectrum shown in Figure 1, the decay gamma emission rates are used as a source that is originating from within the detector volume, and the detector response is tallied using the MCNP6.2 pulse height tally broadened by gaussian energy broadening (GEB) parameters. The GEB parameters were applied from Gallardo et al from a generic HPGe detector [10].

Figure 8 shows the decay gamma emission rates as a function of energy that are the source for the final MCNP6.2 run. These decay gamma emission rates are both from the detector volume and the detector shield.

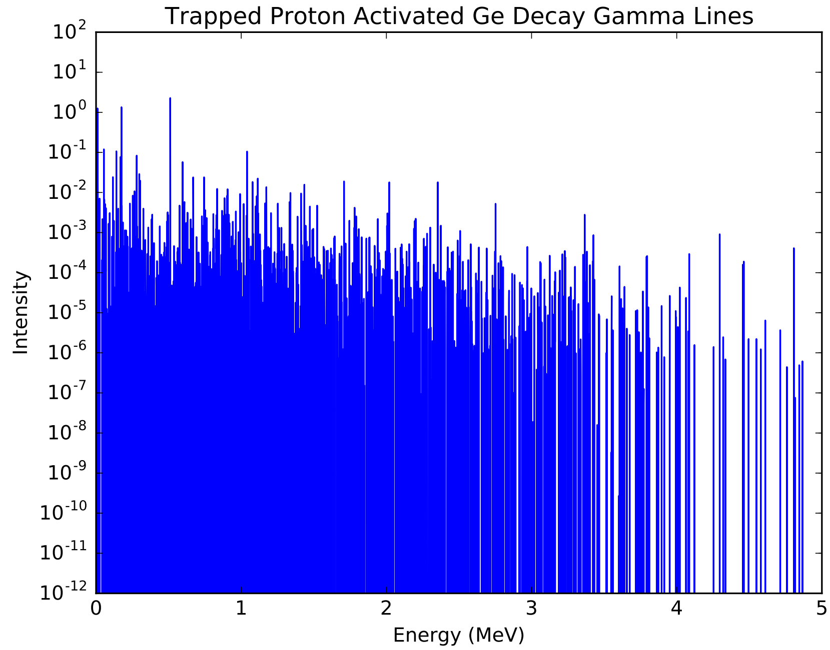

Figure 8: Source SAA proton induced neutron activation decay gamma emission rate

3 Results

Figure 9 shows the final product of the RHESSI satellite HPGe detector spectrum reconstruction effort given in detail above. The simulated HPGe spectrum is compared with the measured spectrum shown in Figure 9 of the Hajdas paper [4]. The discrepancies seen in the two spectra could be a result of the HPGe degradation as a result of exposure to years of cosmic ray fluxes as seen in the measured RHESSI data, that the real detector geometry is of coaxial design and not a solid block of HPGe, there is an unknown amount of aluminum referenced in Hajads' paper located somewhere near the detector that was not included in the simulation or a combination of the proposed sources of discrepancies. The degradation is not included in the MCNP6.2 simulation leading to very distinct, well defined peaks in the simulation and more blurred peaks in the measurement. The MCNP6.2 simulation shows more discrete gamma lines in the lower energy region that could be a result of device-specific electronic processing effects.

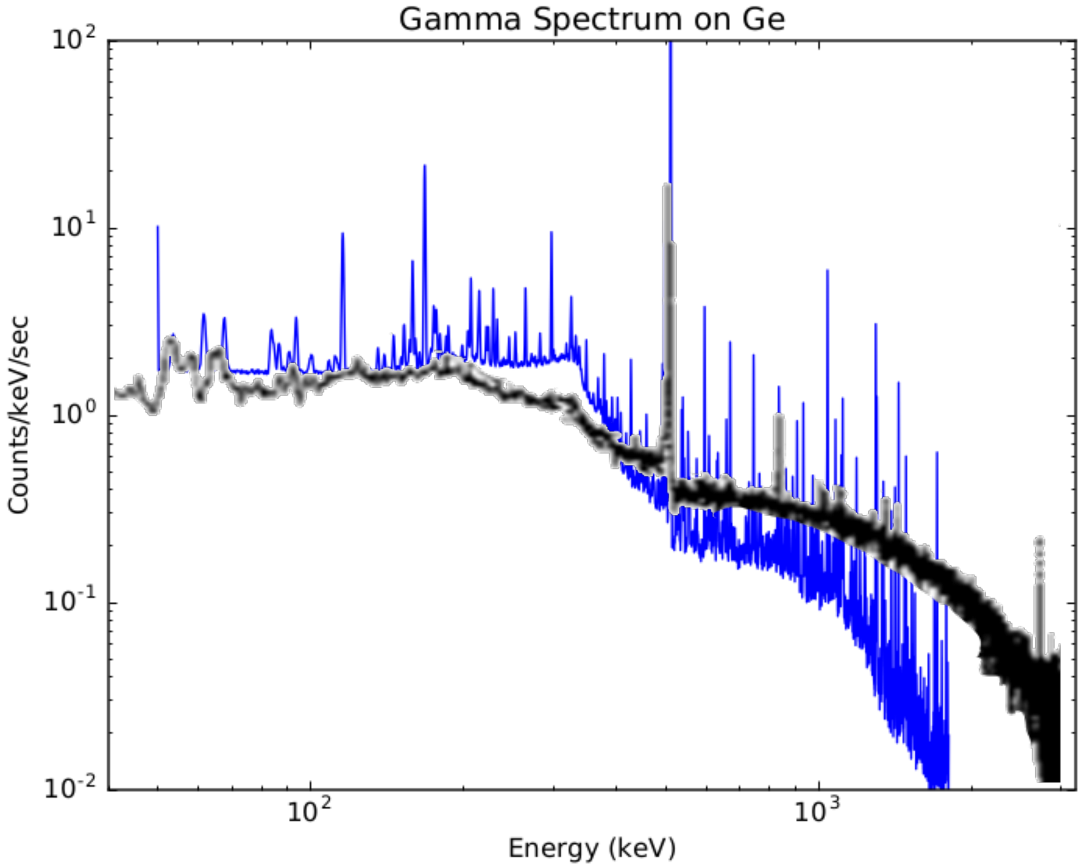

Figure 9: Simulated HPGe detector spectrum (blue) compared with the measured HPGe detector spectrum from Figure 9 in the Hajdas paper (black) [4].

References

[1] B. Micklich, F. Gallmeier, M. Wolhmuther, S. Holloway, E. Iverson, W. Lu, C. Kelsey, M. Mocko, I. Popova, and W. Wilson, "Cinder08 and scripting environment for accelerator activation problems," in *18th Topical Meeting of the Radiation Protection and Shielding Division of ANS, RPSD 2014*, pp. 355–358, 2014.

[2] B. J. Micklich, "Recent improvements to cinder2008 and activation analysis tools." Conference Presentation, July 2017.

[3] B. J. Micklich, F. X. Gallmeier, E. B. Iverson, W. Lu, R. Bergmann, and M. Wohlmuther, "Recent improvements to cinder2008 and activation analysis tools," in *AccApp'17*, July 2017.

[4] W. Hajdas, C. Eggel, C. Wigger, D. Smith, H. Sanctuary, and A. Zehnder, "Spacecraft activation and south atlantic anomaly profiles measured with the rhessi satellite," in *Proceedings of the 7th European Conference on Radiation and Its Effects on Components and Systems, 2003. RADECS 2003.*, pp. 607–610, Sept 2003.

[5] C. J. Werner, "MCNP6.2," Tech. Rep. LA-UR-17-29981, LANL, Oct. 2017.

[6] D. Pelowitz, "MCNPX User's Manual," tech. rep., LANL, April 2011.

[7] G. van Rossum, "Python tutorial," Tech. Rep. CS-R9526, Centrum voor Wiskunde en Informatica (CWI), Amsterdam, May 1995.

[8] D. Smith, R. Lin, P. Turin, D. Curtis, J. Primbsch, R. Campbell, R. Abiad, P. Schroeder, C. Cork, E. Hull, D. Landis, N. Madden, D. Malone, R. Pehl, T. Raudorf, P. Sangsingkeow, R. Boyle, I. Banks, K. Shirey, and R. Schwartz, "The rhessi spectrometer," *Solar Physics*, vol. 210, pp. 33–60, Nov 2002.

[9] F. X. Gallmeier and M. Wohlmuther, "Activation script version 2.0 user guide," Tech. Rep. ORNL/TM-2012/48, ORNL, Oct. 2012.

[10] S. Gallardo, J. Ortiz, F. Pozuelo, C. Pereira, A. Querol, G. Verdu, and J. Rodenas, "Uncertainty analysis in the simulation of an hpge detector using the monte carlo code mcnp5," in *International Nuclear Atlantic Conference*, 2013.