Measurement of
Germanium Detector Efficiency

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ABSTRACT:

A possible discrepancy in the accepted half-life of the radionuclide ^{60}Fe highlights the need for further measurements. The previously accepted value of 1.46 ± 0.27 Myr (Kutschera et al.,) differs greatly from a more recent preliminary result out of Munich, giving 2.43 ± 0.06 Myr. Such a large deviation has serious implications in the field of Nuclear Astrophysics, serving as great motivation to find a true value.

An ^{60}Fe sample was created at the NSCL facility at MSU using projectile fragmentation and subsequent separation of contaminants in the A1900. In this process, ^{60}Co, which happens to be a decay product of ^{60}Fe was also created and implanted on the sample. In order to determine which decay can be attributed to the ^{60}Fe we must find the exact amount of ^{60}Co that is present in plate. This can be determined via gamma spectroscopy. The first step in achieving the ultimate goal is to determine how efficient our gamma detector is. The absolute peak efficiencies of the detectors were previously determined by the efficiency-ratio method using an uncalibrated ^{152}Eu source and calibrated ^{137}Cs, ^{60}Co, and ^{133}Ba sources at 14 cm. My job is to update this information using the same techniques. We have to account for single/double escape peaks, summation, as well as actual decay peaks. This tells us how good the detector is at seeing decays at a specific energy. We also have to take into account the total efficiency of the detector, which tells us how well it sees across a wide energy range from a given sample. This can tell us not only what is found in the peak but how many spurious counts there are from things like Compton scattering, electron escapes etc. Once we have calibrated the detector, analysis of the implanted ^{60}Fe and ^{60}Co samples can begin.

INTRODUCTION:

The study of our universe, more specifically supernovae, has led us to believe that all the elements and isotopes (nuclides), after hydrogen, helium, and lithium, were created in massive stars. Scientist often use deposited materials to gain information about an environment where the material was deposited. The lifetime of a material is used as a measuring stick to reference different events and the passage of time. The ultimate goal of this experiment is to determine the half-life of ^{60}Fe. Extinct ^{60}Fe may serve as a clock of the early solar system through isotopic anomalies of its stable decay product ^{60}Ni. ^{60}Fe has also been detected in an iron meteorite by researchers using Accelerator Mass Spectrometry with a gas-filled magnet. ^{60}Fe may have also played an important role in the early heating of planetary bodies (Kutschera et al.,)

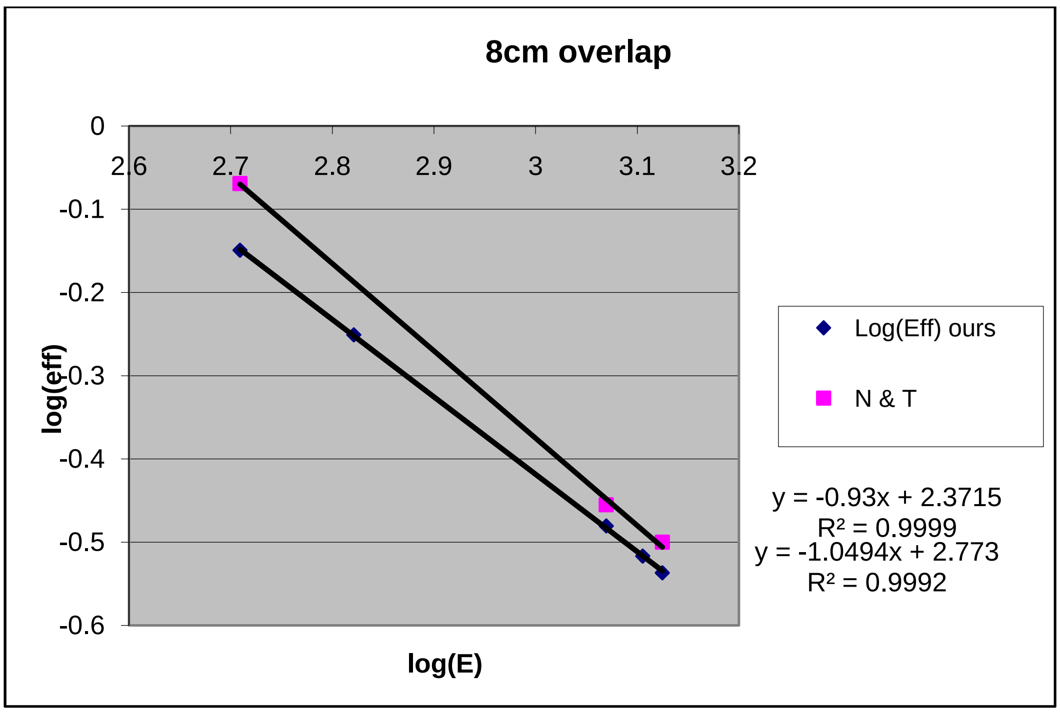
The germanium (Ge) detector is a counting detector and is the instrument that we will be using to count individual gamma emissions from samples. Gamma emissions are direct indicators of decay events. Since we are only using one detector, we are missing most of the decays because they emit gammas in every direction. We already know going into the experiment that our detector will have a total efficiency of no more than 3 or 4 percent and that its peak efficiency will be even lower. Total efficiency tells us how much the detector see across a wide energy range from a given sample. This can tell us not only what is found in the peak but how much other energy from the sample there is from things like Compton scattering, electron escapes etc. Peak efficiency tells us how much the detector see at a specific energy. Both peak as well as total efficiencies should be taken into account to determine the overall efficiency of the detector.

DATA AND DISCUSSION:

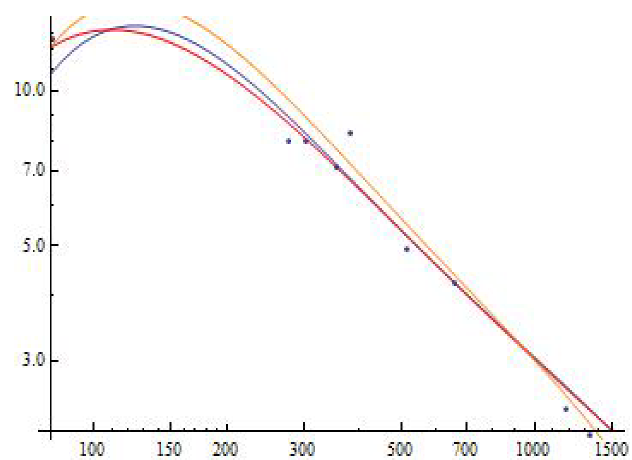
The first data analyzed was the gamma spectrometry of calibrated ^{60}Co and ^{60}Fe implanted samples. The data acquisition program Maestro, showed a full spectrum and included a library of all known radionuclide decay emissions. Wherever there was a peak, the program displayed the energy and what nuclide corresponded to that specific peak, not taking into account the effects of electron escape, cascading effects or the background. Studying of various decay schemes was needed to know the specific decay signatures of the nuclides that we were testing. We looked where we expected to have single escape peaks, double escape peaks, summation peaks, as well as gamma radiation peaks. We had to assure ourselves that we were looking at a confirmed decay event and not something else. The samples were encased in a lead castle to contain the radiation and limit background readings in the detector (see figure 1). There were also multiple slots inside the castle, so we were able to perform tests at 1cm, 8cm and 14cm away from the detector.

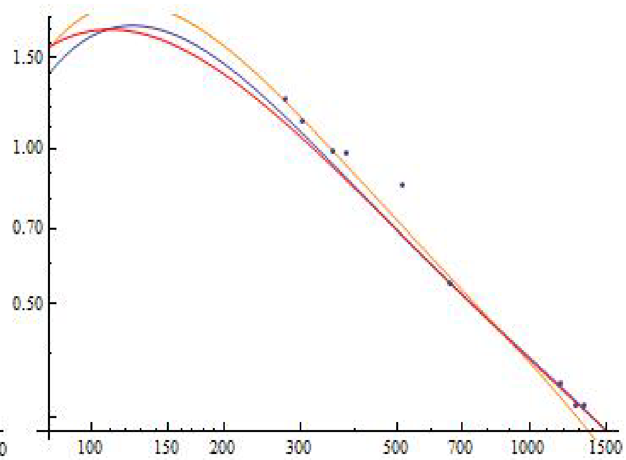
Figure 1: Detector and Lead Castle

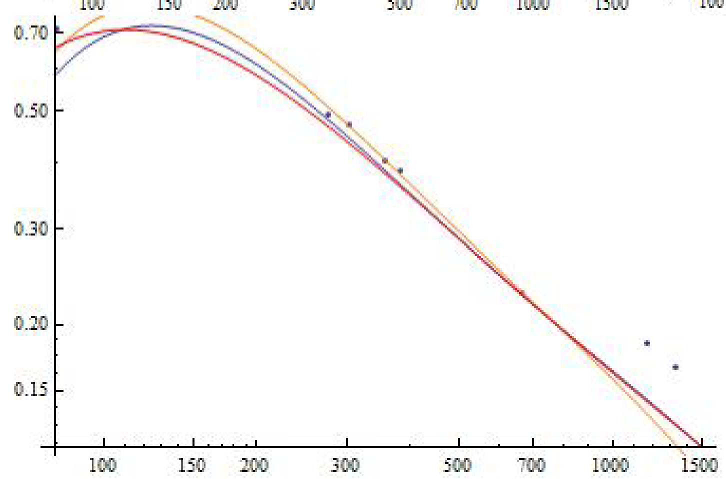
Calibrated samples of ^{22}Na, ^{60}Co, and ^{137}Cs were analyzed at each of the three distances. We then made plots for each run of the Log(Energy) vs. Log(Peak Efficiency). Energy readings were taken straight from the Maestro program and peak efficiencies were calculated using the following formula: $\varepsilon_p = \left(\frac{Counts/sec}{Activity}\right)\left(\frac{100}{I_\gamma}\right)$. The I-gamma term refers to the branching ratios of specific gamma energies; basically a factor that expresses how often we can expect to see a specific gamma irradiation. The activity term also had to be calculated using the following formula: $A(t) = A_o e^{(-ln2)\left(t/t_{\frac{1}{2}}\right)}$. Here, A_o is the initial activity at the time the sample was created, t is the elapsed time from creation to the present, usually in days, and $t_{1/2}$ is the sample's half-life in days. At the end of this calculation, we would have the activity in Becquerel. Below is one example of a plot on Microsoft Excel of our peak efficiencies in comparison to the previously taken data from Nalan and Taygun, a group who performed the same procedure.



The chart shows that our numbers matched up better at relatively higher energies than at lower energies. The five blue data points represent 511, 662, 1173, 1274, 1332 keV and have peak efficiencies of 0.852, 0.548, 0.351, 0.317, and 0.316 percent respectively. The energies represent a single electron escape, ^{137}Cs, ^{60}Co, ^{22}Na, and ^{60}Co respectively. We also did comparisons at 1cm as well as 14cm and the differences between our data and Nalan and Taygun's data grew as we moved further away from the detector. The 1cm data showed an even smaller deviation however, the 14cm run had an average percent difference of 16.6664. The first charts we made depicted a limited energy range. The next chart, created using Mathematica, is a little more complex and encompasses a broader energy range. We first used the Ge detector on an uncalibrated ^{154}Eu source and a calibrated ^{133}Ba source and used Maestro again to find its numerous decay peaks. Our data points included decay peaks from ^{60}Co, ^{133}Ba, ^{154}Eu, ^{137}Cs and the 511keV electron escape energy.







The three charts above are Energy(keV) vs. Absolute Peak Efficiency(%) from 1cm, 8cm, and 14cm respectively. One will notice just by looking at the Y-axis, that the efficiency drops of dramatically as the sample is taken further away from the detector. Furthermore, the efficiency also drops the energy increases. The lines were formed by finding a best fit curve to the data points. After that we did a log-log plot of the best fit curve, and fixed the curves to the 137Cs data point at 662 keV. Each point represents a specific energy peak and the detector's calculated peak efficiency. The three curves on each graph correspond to three slightly different best fit curves and efficiency data. The highest curve at 150 keV represents Nalan and Taygun's results. The middle curve at 150 keV represents my results. The low curve at 150 keV represents the results from Matthew Bowers, a graduate student whom I closely worked with and advised me on various techniques. The three curves were in the same relative position for all three distances. We were mostly interested in the 800 to 1500 keV range and our results clearly show that the curves produced by Matthew Bowers and myself were closer to measured values, with the exception of the 1cm runs. This however, is of little concern because of the greatly increased probability of single and double electron escapes as well as summation peaks that give false signals in the Ge detector. I believe future activity runs will be completed at distances of 8cm and above to eliminate this problem.

FUTURE WORK:

Working on this project showed me how complex this experiment is and each step in reaching our goal of measuring the half-life via Accelerator Mass Spectrometry has its own little experiment within it. Now that the absolute peak efficiency has been calculated, the total efficiency needs to be measured. Once this is done and the detector is calibrated, activity runs on the new 60Fe and 60Co samples can begin. When we have solid activity values, the final stage involving more Accelerator Mass Spectrometry will commence.

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