

Offline Low Level Counting Station

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Abstract: This project involved the construction of an offline low level counting station. This included the lead brick structure to house a germanium detector and sample holder, as well as setting up and testing all electronics. The lead brick structure was built to reduce cosmic and environmental background radiation that impacts the counting done by the detector. The energy calibration and efficiency of the detector while in the lead structure were also calculated using standard calibration sources of known initial activities. Samples of rock salt from New Mexico were tested to compare the gamma radiation from the rocks against the background radiation of the lead structure. Investigating samples like these will help determine whether or not an underground accelerator in that area would be practical. The counting station will be used in the future involving activation measurements in various experiments by both Notre Dame and visiting physicists.

Introduction: The goal of this project was to construct a low level counting station to be used in offline radiation detection. The detection of gamma rays is a crucial aspect within the investigation of nuclear reactions. The Nuclear Science Laboratory (NSL) at Notre Dame conducts many experiments involving the detection of gamma rays. These include online experiments that utilize the three Van de Graff accelerators to investigate reactions in stars as well as low level offline experiments involving different forms of radiation.

Set-Up: Environmental background radiation also contains gamma ray radiation. The gamma radiation can interfere with one's measurement of radioactive samples. Building a lead structure to house a High Purity Germanium (HPGe) detector and sample when measurements are being collected can help reduce the issue. Lead is used because of its high density and large atomic number.¹ When constructing a lead castle to place the detector in, it is important to have multiple layers of lead bricks. With more layers of bricks, more of the cosmic and background radiation from the room can be kept out of the lead castle. The bricks do not always fit together snugly, which can cause a separate issue in which case the gamma rays may stream in through the cracks. However if the bricks are staggered, even by $\frac{1}{4}$ ", the majority of the background gamma radiation would never reach the detector. Ordinary lead does contain natural activity caused by contaminants, so either refined lead or very old sources are better for the construction of castles since these samples would be relatively free of the low level activity. To reduce this, a copper lining throughout the castle is needed (see figure 2). Since the common isotopes of copper are stable, and those that are radioactive do not emit gamma radiation, it will not interfere with the HPGe detector.



Figure 1: The lead castle and Germanium detector set-up located in the NSL.

For the actual measurements, an acrylic sample holder (see figure 3) that would keep the radioactive sources at consistent distances and heights is required. The sample holder is necessary because the distances from the detector to the source need to be reproducible for future experiments. Various shapes of source holders are necessary to account for the different shapes of targets and sources. The different shaped sources need to all have their centers in the same location with regard to the detector, and the holders provide that consistency.

If a radiation source emits several gamma particles during a short amount of time, shorter than the response time of the detector, some counts will be lost during the so-called dead time. Dead time can be described as the minimum amount of time needed between separate events for the counting system to record the events as being separate.¹ Although having the source closer to the detector results in more counts, the dead time will increase because the detector will need more time to process the increased number of counts.

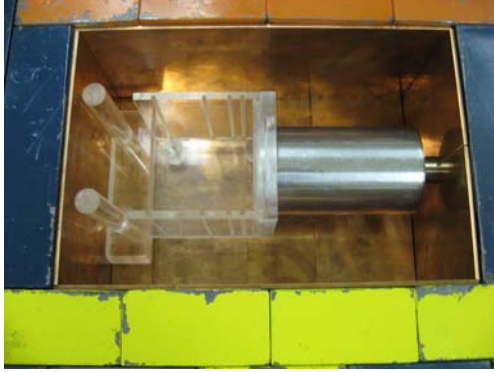


Figure 2: The inside of the lead castle.

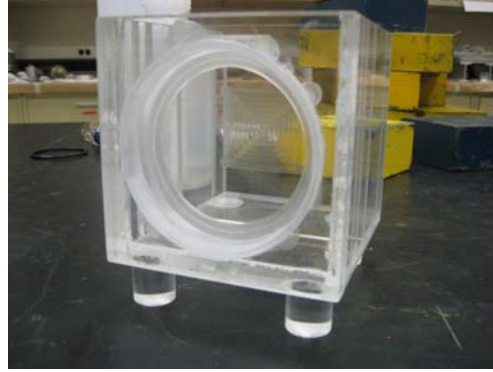


Figure 3: The acrylic sample holder.

The electronics necessary include a power supply, pre-amplifier, amplifier, analog digital converter (ADC), and the acquisition system. The power supply connected to the detector also includes a remote shutdown which will shut down the detector if its temperature reaches a critical limit. The pre-amplifier handles the detected signal which relays the signal to the amplifier. The amplifier provides the final signal shape that is processed by the ADC and acquisition system (in this set-up, ASPEC 927 Dual Multichannel Buffer). To run the acquisition system, Maestro-32 MCA Emulation software was used.

Experiment: To begin, a ^{60}Co calibration source of known initial activity was used to determine the amplifier to use for the counting station. Of the four slots in the sample holder, the second one was chosen to be sure it was close enough to detect counts in a shorter amount of time, but far enough away to hopefully avoid the summing of the two gamma energies. Five amplifiers were tested at various numbers of channels, coarse and fine gain settings, and shaping times. The ^{60}Co was placed in the lead castle and data was collected for approximately five minutes for each test run. At this time, the known peaks of 1173 keV and 1332 keV were located and analyzed using the mark peak function in Maestro. The full-width half-maximum (FWHM) of the uncalibrated channels was noted for each peak for the various runs. A FWHM as small as possible was the goal, as a peak that approaches a mathematical delta function has much less variation in the pulses that are recorded at the same energy. It was obvious right away that the

lower number of channels would not suffice for further test runs, so 16384 channels (16k) and 8192 channels (8k) were predominately tested. After 24 runs, the first amplifier was chosen with a shaping time of 3 μ s, a coarse gain of 20, and a fine gain of 9.2. Once this was established, long background runs both with and without the lead castle lid were done at 16k channels to get an idea of whether or not the shielding was performing well.

Four common calibration sources, Sodium-22, Cobalt-60, Barium-133 and Cesium-137 were tested for approximately 300 seconds at each of the four sample holder slots at 16k channels. This was completed to begin finding the channels where the peaks of the various sources would occur. However, optimal FWHM has been found with 8k channel spectra, since 16k spectra were not satisfactory. When the switch in the number of channels was made, the runtime was extended to 1200 seconds to obtain more counts, regardless of the distance from the detector. Background runs with and without the lead castle lid also needed to be completed again to be sure that the runs with and without samples were comparing the same channel range.

Analysis: Upon completion of the runs of the calibration sources at the four distances, the location of the peaks of the gamma energies needed to be found to determine the calibration of the channels in terms of energy. The following results were obtained:

Sample	Energy (keV)	Branching Ratio, I_γ (%)	Channel Range
¹³³ Ba	276.440	0.07164	403-411
¹³³ Ba	302.851	0.1833	442-450
¹³³ Ba	356.013	0.6205	521-529
¹³³ Ba	383.848	0.0894	561-569
¹³⁷ Cs	661.657	0.8510	970-978
²² Na	1274.530	0.99941	1872-1880
⁶⁰ Co	1173.237	0.9985	1723-1731
⁶⁰ Co	1332.501	0.9998	1957-1965

Figure 4: Energies and branching ratios of emitted gammas of various samples and the channel ranges.

The number of counts detected for each run was recorded, as well as the real time of the measurement and the dead time percentage. The counts used were the gross area of the counts at

the given channel range. Because of the dead time, during which the detector could not process another count, the number of counts detected is not correct. This was corrected for each peak for each sample using the following equation:

$$N_{\text{det}}^{\text{corr}} = \frac{N_{\text{det}}^{\text{uncorr}}}{\left(1 - \frac{DT}{100}\right)},$$

where DT is the dead time as a percentage. The dead time for each run was less than 0.95%, but the correction was still taken into an account.

Using the channel ranges obtained from the calibration sample runs, the background counts at those ranges could be found. These were recorded for both with and without the lead castle and corrected in the same manner as the counts for the calibration sources. Taking the measurement run time into account, the background counts per second for each channel range were determined for with and without the lid. This would be helpful in determining the background counts present for the test runs of the calibration sources, which had much shorter run times than the background runs. These rates were also compared as a ratio of the counts per second without the lid to with the lid.

Gamma radiation from three particular backgrounds were looked for: Potassium-40, Bismuth-214, and Thallium-208 with energies of 1460.83 keV, 1120.294 keV, and 2614.511 keV, respectively. Upon comparison of the counts detected without the lead castle lid to the counts detected with the shield, it was found that there was approximately 140 times as much ^{40}K , 50 times as much ^{214}Bi , and 25 times as much ^{208}Tl when the lead castle was not completed. In comparing figures 5 and 6 below, it can be noted that many of the smaller background peaks were eliminated by adding the lead castle lid, as was expected.

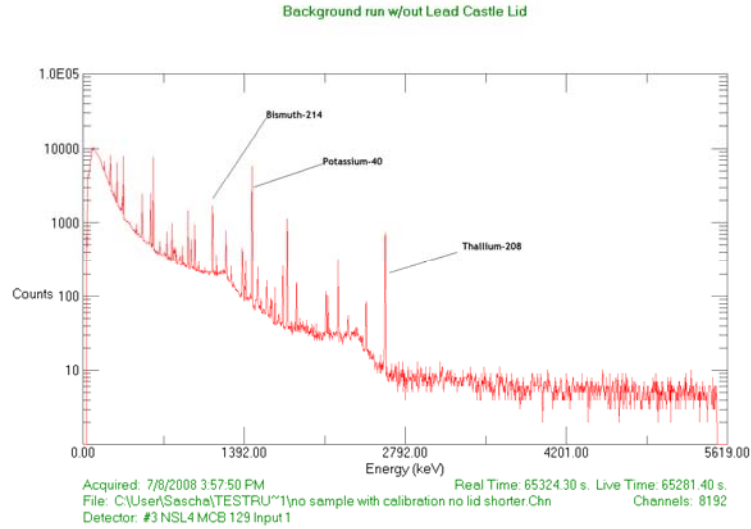


Figure 5: Background run of lead castle without a completed lid.

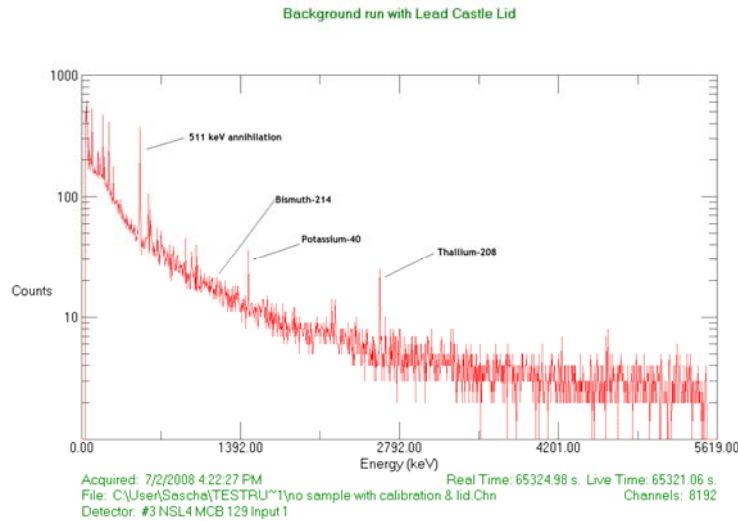


Figure 6: Background run of lead castle with a completed lid.

In order to determine the efficiency of the counting station, the number of counts that should be emitted from the given radioactive sources needed to be determined. In order to do this, the initial activity, half-life, and creation date of the samples were necessary. They are as follows:

Sample	Creation Date	Half-life (years)	Initial Activity
¹³³ Ba	15 April 2005	10.51 ± 0.05	3.756 kBq
¹³⁷ Cs	1 Aug. 2007	30.07 ± 0.03	3.752 kBq
²² Na	15 Aug. 2004	2.6019 ± 0.0004	3.532 kBq
⁶⁰ Co	1 Jan. 1969	5.2714 ± 0.0005	10.00 µCi

Figure 7: Calibration source activities, creation dates and half-lives.

Once the number of days since creation and half-life were converted to seconds, the activity of the sources were calculated using the following equation,

$$A = A_0 e^{-\lambda t}, \text{ where } \lambda = \frac{\ln(2)}{t_{1/2}}.$$

Using the activity of the source and the branching ratios of the gamma energies, the number of expected counts emitted by the various sources could be determined using:

$$N_{emitted} = AtI_{\gamma},$$

where t is the real running time in seconds and I_{γ} is the branching ratio as a percentage (see figure 4). Once the number of expected counts for each gamma energy is known, the efficiency of the detector can be calculated by simply dividing the detected counts by the expected counts for that energy. This was done for each of the distances / sample holder slots to compare the efficiencies of each slot.

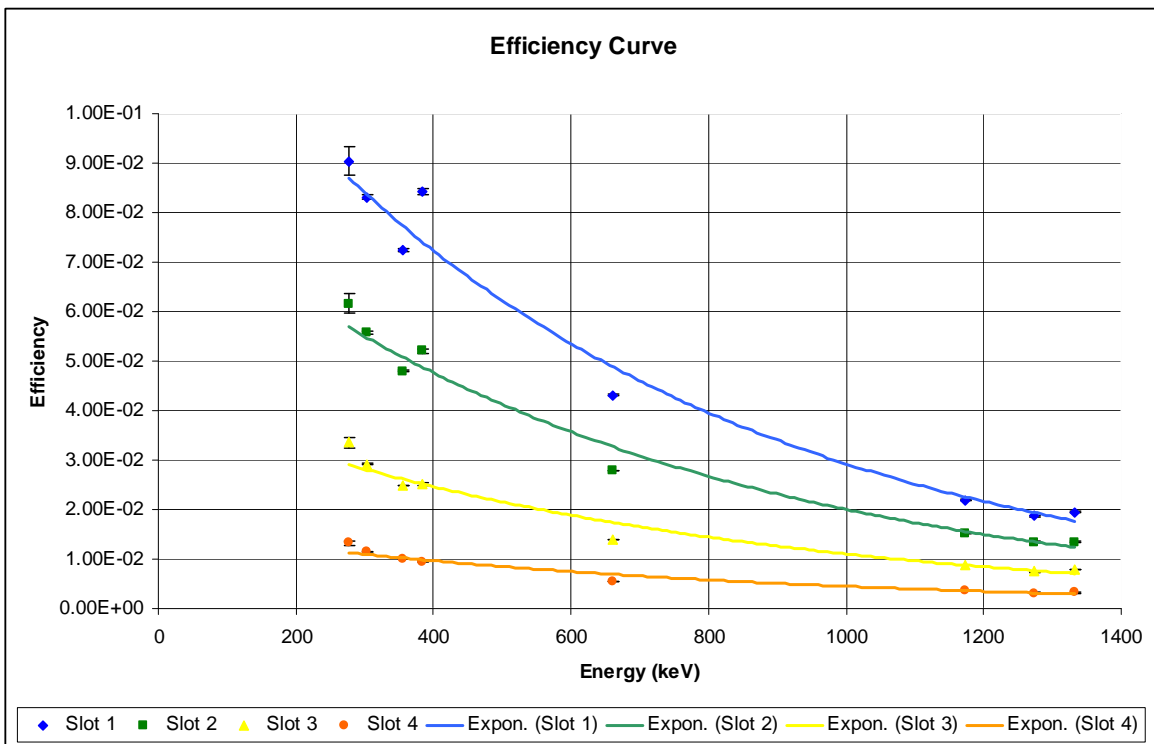


Figure 8: Efficiency curves for each distance using ^{22}Na , ^{60}Co , ^{133}Ba , and ^{137}Cs .

For each of the distances it can be observed that the efficiency of the detector goes down as the energy of the gamma ray goes up because there is a lower chance that a higher energy gamma will interact with the detector.

Rock Salt Samples: The main purpose of the lead castle is to block out cosmic rays and background radiation. In order to eliminate the step of building a lead castle, the possibility of putting accelerators underground to eliminate more cosmic rays has been discussed. Samples of Permian Age rock salt from the Carlsbad, New Mexico Waste Isolation Pilot Plant (figures 9 and 10) were crushed and tested to see if the rocks that make up the walls there contain a considerable amount of background radiation. In comparison to the background runs with the lead castle, the amount of radiation coming from ^{40}K , ^{214}Bi and ^{208}Tl was only slightly higher than without the rock samples.



Figure 9: Gray rock salt



Figure 10: Red rock salt

Conclusions: Constructing a lead castle to house a Germanium detector is quite beneficial when conducting low-level counting experiments because of the impact it has on shielding the source from background radiation that can impact the results. The option of conducting work underground is also useful if the rock walls in the locations do not affect the background radiation.

Future Work: The counting station will have a great deal of use for two main experiments in the near future, and probably more down the road. One being for activation measurements of $^{51}\text{V}(p,n)$, while the other is for the activation measurement of $^{114}\text{Sn}(\alpha,\gamma)$.

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References:

¹ Knoll, Glenn F. *Radiation Detection and Measurement 3rd ed.* Wiley: New York, 2000.