Nuclear Spectroscopy

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Objective

The purpose of this lab was to examine the decay spectrum of radioactive materials (particularly Cesium, Americium, Cobalt and Strontium) using the CASSY equipment and study the effectiveness of radiation absorbers of varying thicknesses.

Setup and Apparatus

This experiment was carried out on a specialized platform that integrated the hardware components with a graphic user interface and displayed data in a user-friendly format. The components of this setup are described below:

- **Detector and Scintillator** The detector stage is placed below an inverted "thermos bottle" structure which contains the scintillator and the photomultiplier tube. This is where the radioactive materials are placed. The radiation travels from the detector to the Scintillator which consists of a sodium iodide crystal that has been doped with Thallium and is transparent to 3eV photons.
- **Photomultiplier** The photomultiplier amplifies the detection pulse so that it can be recorded by the electronic equipment. The photons entering the photomultiplier strike a photo-cathode and release electrons. These electrons are drawn to a dynode which amplifies this electron pulse. A cross section of this can be seen in the figure 2 The number of electrons produced is approximately proportional to the energy of the incident particles.
- **Multi-Channel Analyzer** The Multi-Channel Analyzer converts the pulse heights to a digital address proportional to it. A plot of the register counts against the respective addresses effectively provides an energy distribution.
- **Sensor-CASSY** CASSY Interfaces with the computer and accepts voltage or current input directly and turns it into plots for the user.
- **Lead Bricks** Lead bricks block background radiation from entering the Detector-Scintillator setup.

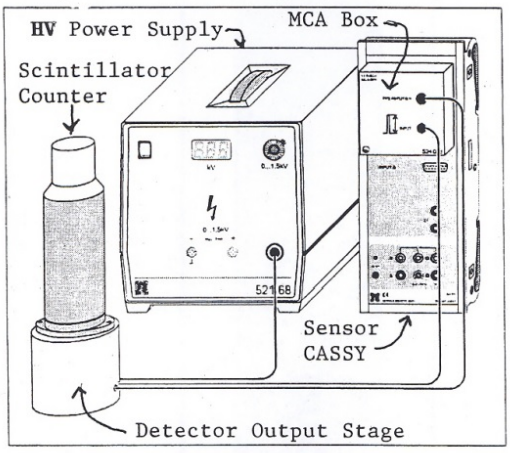

Figure 1: CASSY Apparatus Hardware

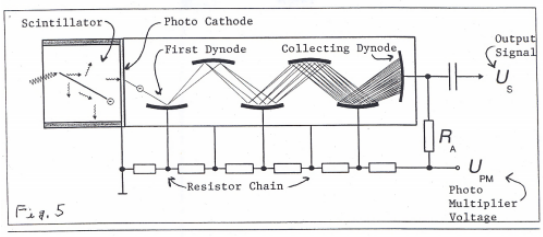

Figure 2: Photomultiplier Cross Section

The apparatus needed to be calibrated for the energies detected. Since there was no point of zero reference, we required two points of known energy on any spectrum to act as reference points: one to provide a reference point of "zero" radiation and a second to scale the detected radiation energies. Using this calibration, it was possible to obtain meaningful data from the plots in the CASSY interface. There were four radioactive sources considered for this experiment:

- Cesium-137
- Americium-241
- Cobalt-60
- Strontium-90

The known energy peaks of Cesium (at 662 keV) and Americium (at 60keV) were used for calibration.

Theory

Different materials emit radiation of different forms:

- **Alpha particles** These consist of two protons and two neutrons
- **Beta particles** These are high-speed/high-energy electrons or positrons and have much higher energies than alpha particles and interact less with the medium they travel in.
- **Gamma radiation** These are very high energy electromagnetic radiations. They have much higher energies than beta particles and interact with their medium even less than beta particles. The NaI(Tl) crystal used for this experiment is transparent to the photons (but not to the alpha or beta particles) which is why the electrons produced by the photoelectric effect and Compton scattering were needed to measure these energies.

This experiment detects radiation using the energies of photons released due to the alpha or beta particles or from gamma radiation. A beta particle passing through the scintillator crystal, however, interacts with the crystal and is therefore slowed down. The energy of the incident electron is proportional to the number of electron-hole pairs created in the crystal and the ionization of the Thallium produces photons of about 3eV. Incident gamma particles produce electrons by the photoelectric effect or by Compton scattering and these electrons in turn interact with the scintillator in the same way as beta particles. The photomultiplier amplifies the pulse for easier detection.

Procedure and Data Collection

Emission Spectrum for Cesium-137, Americium-241, Cobalt-60 and Strontium-90

1. The Cesium source was placed on the detector stage ad the input voltage was set to 600 V
2. The capture time window was set to 20 s and an initial gain of 1x was used to take a sample spectrum.
3. The gain slider was adjusted until the plot produced by one sample spanned enough of the screen width to provide a reasonable resolution of the relevant data.

4. Keeping the gain constant, the voltage was changed to 550 V in order to show the relationship between input voltage and the energy of the emergent electrons and as shown in below, the plot shrinks horizontally demonstrating that the energies of the electrons radiated depends on the Voltage applied

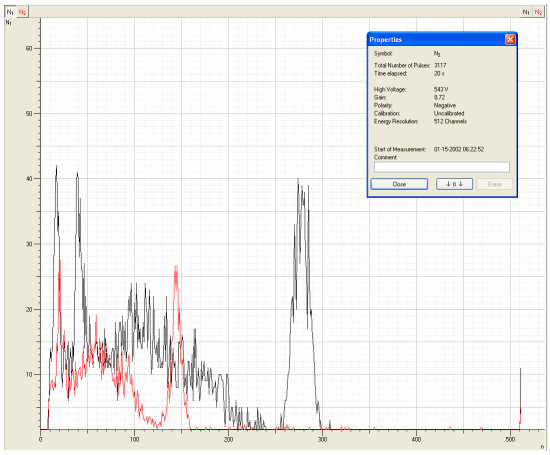

Figure 3: Cs radiation energy plots at 600 V (in black) and then at 550 V (in red)

5. Reverting to the 600 V, the Cs and Am spectrums were recorded on a single plot for calibration. The Cesium peak was saved as 662 keV and the Americium peak was saved as 56 keV

6. The recorded data was cleared and a new spectrum was recorded without any source both with and without the lead bricks to observe the shielding effect of the lead bricks from background radiation. This resulted in the energy plot seen below

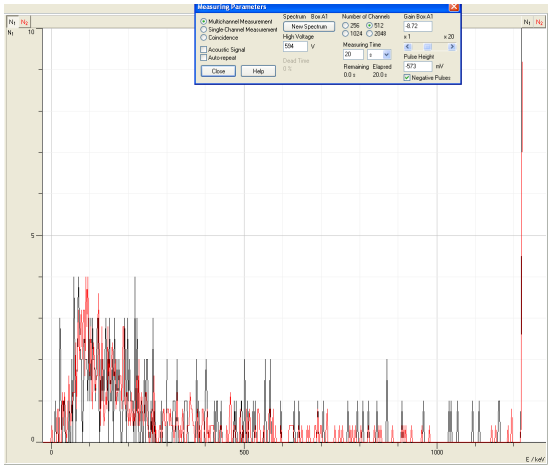

Figure 4: Background radiation spectrum without shielding (in black) and then with (in red)

7. A new cesium spectrum was recorded with the lead shielding in place and the energy plot without a source was subtracted from this plot resulting in a spectrum that corresponds approximately to the cesium spectrum without any background radiation. This resulting

spectrum (as seen below) yields some negative values of energy because background radiation is not a constant fixed radiation, but it provides a closer approximation of the Cesium spectrum than the plots with the background radiation.

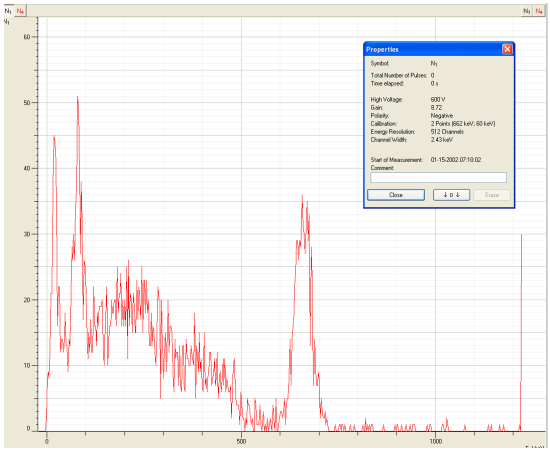

Figure 5: Cs radiation spectrum after adjusting for background radiation

8. The same process was repeated for the Cobalt source giving the spectrum in the figure below. The data recorded was much noisier than previous data sets and despite adjusting the gain multiple times, we were unable to fit the Cobalt peaks of 1.1 MeV and 1.3 MeV:

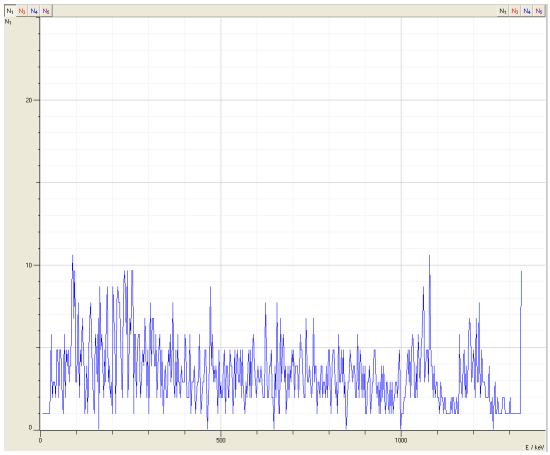

Figure 6: Cobalt radiation spectrum after adjusting for background radiation

9. The same experiment was once again repeated for Strontium to get the following data plot. This data plot shows the energy peak much more clearly since the gain was adjusted to fit all the data in the visible region of the plot.

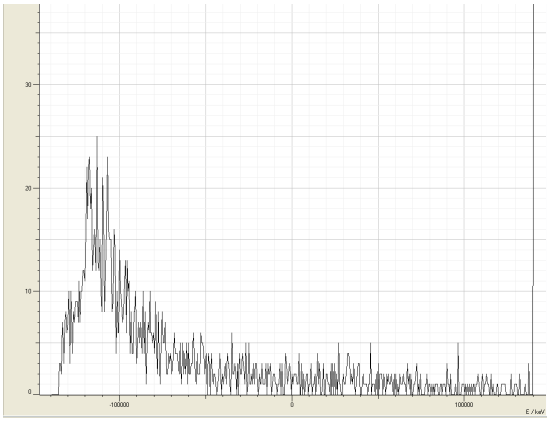

Figure 7: Strontium radiation spectrum after adjusting for background radiation

Aluminum Absorbers

1. Due to time constraints and problems with the software, we were only able to test the efficiency of aluminum absorbers of varying thicknesses with a Cobalt source. The Cobalt source was placed in the Detector with the absorbers inside and the resulting plots can be seen below. Since our data points were lost, we were unable to perform any quantitative data analysis for the absorption efficiency of aluminum at different thicknesses but, as is clear from the plot, the emission spectrum had much higher energies for the thinner (0.3 cm) than for the thicker (1.2 cm).

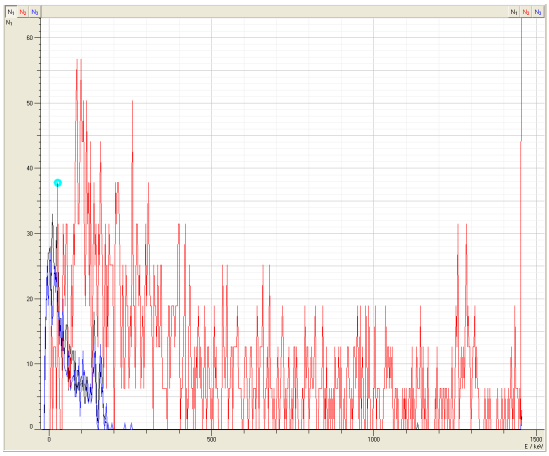

Figure 8: Cobalt emission spectrum with Aluminum absorbers of 0.3 cm (in red) and 1.2 cm (in blue)

2. Comparing the above plot to the initially recorded emission spectrum for Cobalt Figure **??**) shows clearly that the absorbers effectively absorb higher energy radiations, and do so more effectively as the thickness of the absorber is increased.

Questions

Are the bricks reducing the background?
The lead bricks visibly reduce the radiation recorded in the higher energy ranges (as can be seen in Figure 4)
Is the plot (of ln **of number of counts against the thickness of the absorber) pretty much a straight line?**
Since we were only able to test two thicknesses of absorbers, and were unable to collect any data points an exponential approximation of approximated data would be highly unreliable. The noise in the collected data would add to the already numerous uncertainties in any definitive analysis of this part of the experiment. The number of counts does clearly have a higher-order dependence than a linear function
How does the absorption coefficient depend on the mass density of the absorber?
Since we were only able to perform the absorption part of the experiment with different thicknesses of Aluminum, there was no recorded data to show this empirically, but given that higher energies resulted in a larger number of emitted electrons, it would seem logical that materials of higher density would by better absorbers.
How does the absorption coefficient depend on the energy of the gamma ray?
Although we were unable to corroborate these results with the energy spectra of different materials, in the Cobalt-60 spectrum alone, the aluminum absorbers appeared to be less effective in the higher frequency ranges.
Show that a photon cannot be completely absorbed by a stationary free electron. Use relativistic formulae.
We know that:

- Initial energy of a photon (gamma radiation): $E_\gamma = p_\gamma c$
- Intial energy of an electron: $E_e = \sqrt{p_e^2c^2 + m_e^2c^4} = c\sqrt{p_e^2c + m_e^2c^2}$
- Final energy of the electron: $E_f = m_e c^2$

By conservation of energy:

$$E_f = E_\gamma + E_e$$

$$E_f = E_\gamma + \sqrt{p_e^2c^2 + m_e^2c^4}$$

$$m_e c^2 = E_\gamma + \sqrt{p_e^2c^2 + m_e^2c^4} = E_\gamma + m_e c^2\sqrt{\frac{p_e^2c^2}{m_e^2c^4} + 1}$$

Which would be a contradiction since E_γ is a positive quantity

Conclusion

We understood how to operate and calibrate the electron spectrometer and analyze the radiation spectrums and analyzed the differences in energies of radiation emitted from various materials. We noted the difference in emission spectrums with and without the lead shield blocks and noted that they did block some background radiation and were more noticeably effective in shielding from higher energy radiation.
We measured the emission spectrum of Cobalt with Aluminum absorbers of varying thickness and saw a distinct drop in the energies of the radiations detected with an increase in thickness which supported our hypothesis that thicker materials act as better absorbers.

With more time to perform this experiment, it may have been possible to use absorbers of different materials as well as the same absorbers with different sources to note the effectiveness of various absorbers at different energies with the dependence on thickness of the absorber. This would have allowed for a more comprehensive analysis of the emissions and absorptions and the individual characteristics of the materials that these properties may depend on.