How does the distance from a neutron source of ^{241}Am-Be affect the isotopes created by the activation of ^{27}Al?

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1 Introduction

Neutrons are subatomic particles with no charge, allowing them to travel much further without interacting with other particles, making them difficult to detect [1]. When a neutron does interact, it can cause secondary reactions within the nuclei, or transfer some of its energy to the collider, which may also release some form of radiation [1]. Neutrons are classified on their energy as being thermal ($E = 0.025$ eV), epithermal (0.025 eV $< \mathrm{E} \leq 0.1$ MeV), or fast ($\mathrm{E} > 0.1$ MeV) [2]. The experiments in this report rely on the interactions of thermal neutrons.

An Americium-241 - Beryllium-9 (^{241}Am-Be) source is placed at the bottom of a large container surrounded by water in order to reduce the effects of radiation and to reduce the energy of the neutrons as much as possible. Surrounding the source in the container, and in the water, are three Aluminum-27 rings, stacked one on top of another.

The objective of this report is to determine the possible isotopes created by the neutron activation of ^{27}Al and the effects of distance relative to the ^{241}Am-Be source have on these isotopes and their decay curves.

2 Theory

Neutrons are difficult to obtain from a single isotope, as none exist or are known at this time. However, it is possible to create them reliably from combining the α-particles emitted by ^{241}Am with ^{9}Be, which results in the chain described in Equation 1 [3].

$$\begin{aligned} {}^{241}\mathrm{Am} &\rightarrow {}^{237}\mathrm{Np} + \alpha \\ {}^{9}\mathrm{Be} + \alpha &\rightarrow {}^{13}\mathrm{C}^{*} \rightarrow {}^{12}\mathrm{C} + n + \gamma \end{aligned} \tag{1}$$

When ^{27}Al is "hit" by a neutron it undergoes radiative capture of the form $^{27}\mathrm{Al}(\mathrm{n},\gamma)^{28}\mathrm{Al}$ [2]. The ^{28}Al isotope that is created is unstable and quickly decays into ^{28}Si via β^{-} decay [2].

The decay of radioactive nuclei follow the exponential decay law, as described in Equation 2 [1].

$$N(t) = N_0 e^{-\lambda t} \tag{2}$$

where $N(t)$ is the number of nuclei present at a time t, and N_0 is the number of nuclei at $t = 0$. The decay constant λ is related to the half life of the isotope through Equation 3 [1].

$$t_{1/2} = \frac{\ln 2}{\lambda} \tag{3}$$

Since the emission rate of γ-rays is directly proportional to the amount of nuclei present in the source, Equations 2 and 3 can be analogous to the counts recorded by the detector, which allows for the properties of the isotope to be determined.

3 Methods

Before getting measurements from the neutron activated source, the detector which is to be used needs to be properly calibrated as to ensure the right energy levels are captured. To calibrate the detector, spectra of the isotopes of ^{137}Cs, ^{22}Na, and ^{60}Co were taken, as these sources have well defined photopeaks that occur at documented energies [4]. More information on the calibration process can be found in [5].

Once the calibration data is acquired, an ^{27}Al ring that has been sitting in the neutron bath for at least an hour is selected and removed, quickly dried, and moved to a detector station in order to begin measuring the γ-rays that are emitted by the isotopes created by the neutron activation. A total of 360 spectra are taken, each lasting for 10 seconds in order to build a time dependent profile of the decay of the isotopes, which is subsequently analyzed.

4 Data and analysis

Figure 1 shows the combined spectra across all the runs of the different sources of ^{27}Al. The analysis around the isotopes that make up the spectrum in Figure 1 will be done using the data obtained from the bottom source.

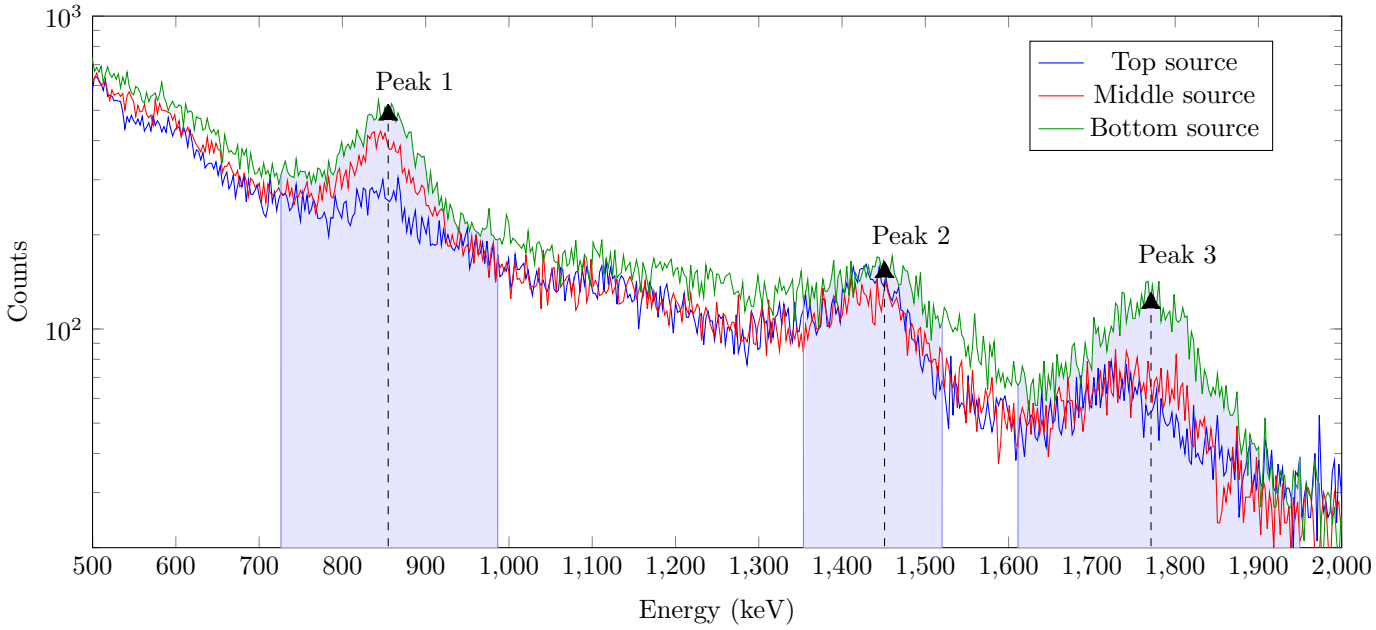

Figure 1: Spectra of the combined counts from running the detector for an hour of the top, middle, and bottom sources of ^{27}Al restricted between 500 keV and 2000 keV to better highlight the areas of interest. Each source was activated for a period of more than an hour. The highlighted blue regions indicate the range chosen for each of the corresponding labeled energy peaks located above the center of each region. Peak 1 has an energy of 855 ± 21 keV, Peak 2 is 1456 ± 27 keV, and Peak 3 is 1771 ± 32 keV.

It is apparent from Figure 1 that, as the ^{27}Al source moves further away from the neutron emitter, peaks 1 and 3 decrease by noticeable amounts, which points to these energy peaks as being intrinsically linked to the neutron activation of the source. However, peak 2 does not appear to be heavily affected by the distance variations of the ^{27}Al source, instead remaining relatively constant across the three measurements.

Peak 2 appears to sit on the Compton edge of ^{28}Al [6], which might cause it to be overlooked at first. As the source moves further away from the neutron emitter, the intensity of ^{28}Al also decreases, which also affects its Compton continuum and Compton edge [1]. If peak 2 was only caused by this isotope, then it should also decrease in strength, yet it does not, leading to the idea that the isotope behind this energy peak is independent of the neutron activation, and might likely originate from the ^{27}Al source itself in the form of an imperfection in the material used to make it.

4.1 Half life of isotopes

In order to avoid unforeseen consequences in determining the value of the half life of an isotope, its decay curve should be linearized [2], which can be achieved by using Equation 4. A weighted linear least squares method is used in order to obtain the fit parameters.

$$\ln\left(N(t) - B\right) = -\lambda t + \ln N_0 \tag{4}$$

The background B is determined by using the decay curve of ^{28}Al. Since this isotope has a short half life, it will eventually stop being the primary emitter in the region, meaning that anything picked up by the detector will most likely come from the background. Since it is expected that the background is constant, a weighted average [8] can be performed on all the points located after a time in which the ^{28}Al emission can be considered as negligible.

The process of determining the half life for Peak 1, corresponding to the decay of ^{28}Al, is described in Figure 2. The methods used in that case are applied to the remaining two peaks, which will narrow down the options on what isotopes are likely to be the origin of the energy peaks.

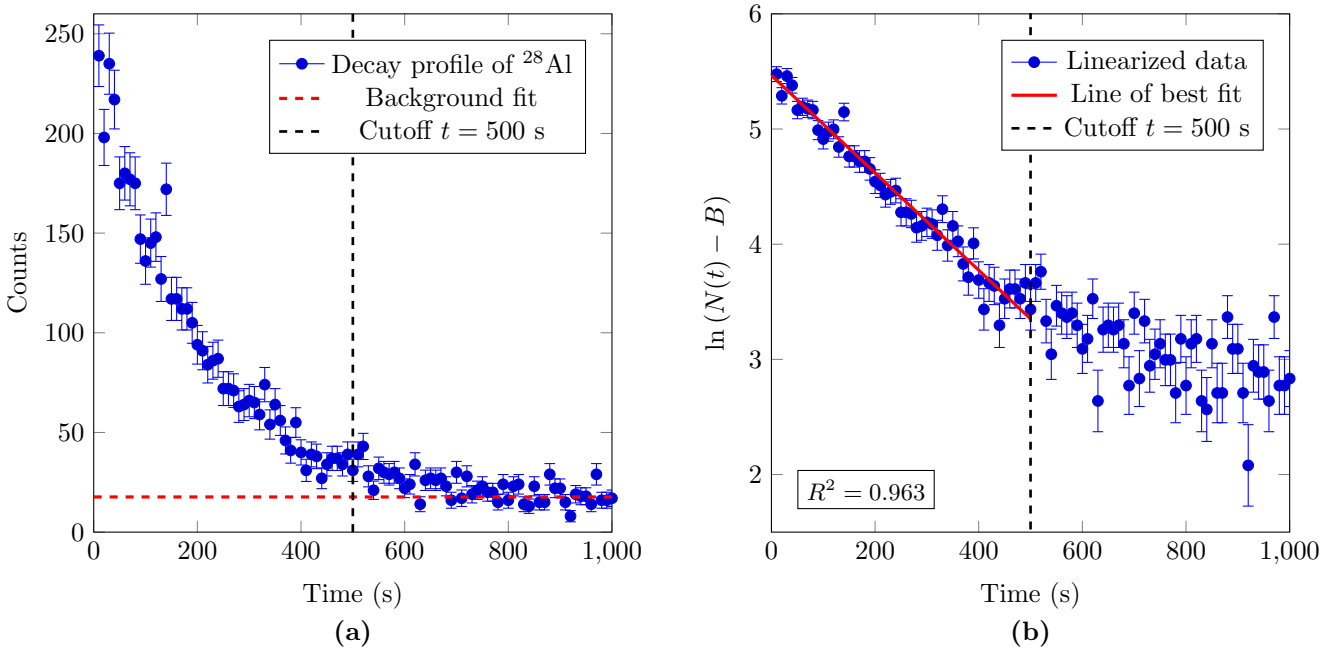

Figure 2: Plots showing the decay of Peak 3 from Figure 1. Figure 2a represents the exponential decay curve of the isotope, as depicted by Equation 2, while Figure 2b depicts the linearized version of the data using Equation 4. From looking at **(b)**, it was decided to only fit the points from 0 to 500 seconds, as from that time onward the data starts to fluctuate more. It is also from this time stamp up until 3600 seconds that the background average is taken, shown in **(a)** to be 18 ± 1 counts. The resulting best fit line was characterized as $\ln(N(t) - B) = (-4.23 \pm 0.11) \times 10^{-3}\ t + (5.465 \pm 0.024)$, with a fit value $R^2 = 0.963$.

Using the procedures from Figure 2, Peak 3 was found to have a half life of 2.731 ± 0.071 min. As mentioned previously, Peak 2 can be considered to be independent of the decay of ^{28}Al, despite residing on its Compton edge, though analysis of the linear data revealed the necessity to extend the cutoff from 500 to 550 seconds in order to capture the necessary data. It was found to have a half life of 3.182 ± 0.074 min.

The process used in Figure 2 is slightly different for the case of Peak 1, as it sits on top of the Compton continuum of the other two peaks, analyzing the decay curve within the half life of the other two peaks will likely result in an incorrect fit. Instead, the time range is constrained from 200 to 700 seconds, as this will ensure that the effects of the other peaks are minimal while also preventing on over-fit of background noise from taking a later sample. Doing this results in a half life of 11.2 ± 1.0 min.

4.2 Possible isotopes

With the energy and half life data acquired, a list of which isotopes are potentially responsible for creating them can be narrowed down. First up, Peak 3 most likely corresponds to the decay of ^{28}Al, which has an energy peak at 1778.987 ± 0.015 keV and a half life of 2.245 ± 0.002 min [4]. Though the energies are in agreement, the half lives are not, but there are no other likely candidates that could be found to fit both criteria. Additionally, ^{28}Al is the principle isotope created during the activation process of ^{27}Al [2].

Peak 2 is thought originate from ^{52}V, which has an energy peak at 1434.06 ± 0.01 keV and a half life of 3.473 ± 0.005 min [4]. The reason behind this choice is that vanadium is used in the production of aluminum alloys [9]. Since it was never specified that the sample of ^{27}Al were pure, it is entirely possible that some ^{51}V was used in the production, or was present beforehand. Either way, ^{51}V is subject to neutron activation, which undergoes the reaction $^{51}\mathrm{V}(\mathrm{n},\gamma)^{52}\mathrm{V}$ [10].

Peak 3 is likely to be related to the decay of ^{27}Mg, which has an energy peak at 843.76 ± 0.10 keV and a half life of 9.485 ± 0.012 min [4]. This choice is justified through the $^{27}\mathrm{Al}(\mathrm{n},\mathrm{p})^{27}\mathrm{Mg}$ reaction, which is a consequence of the activation of ^{27}Al [7].

4.3 Effects of distance from neutron source

As was seen in Figure 1, there is a link between the intensity of the energy peaks and associated phenomena with the distance from the ^{241}Am-Be source. One of the effects this has is that collecting information on the decay curves, and thus the half life, becomes incredibly difficult. An example of this is shown in Figure 3, which shows the exponential and linearized decay curve of the 1771 keV peak of ^{28}Al from all of the different ^{27}Al sources.

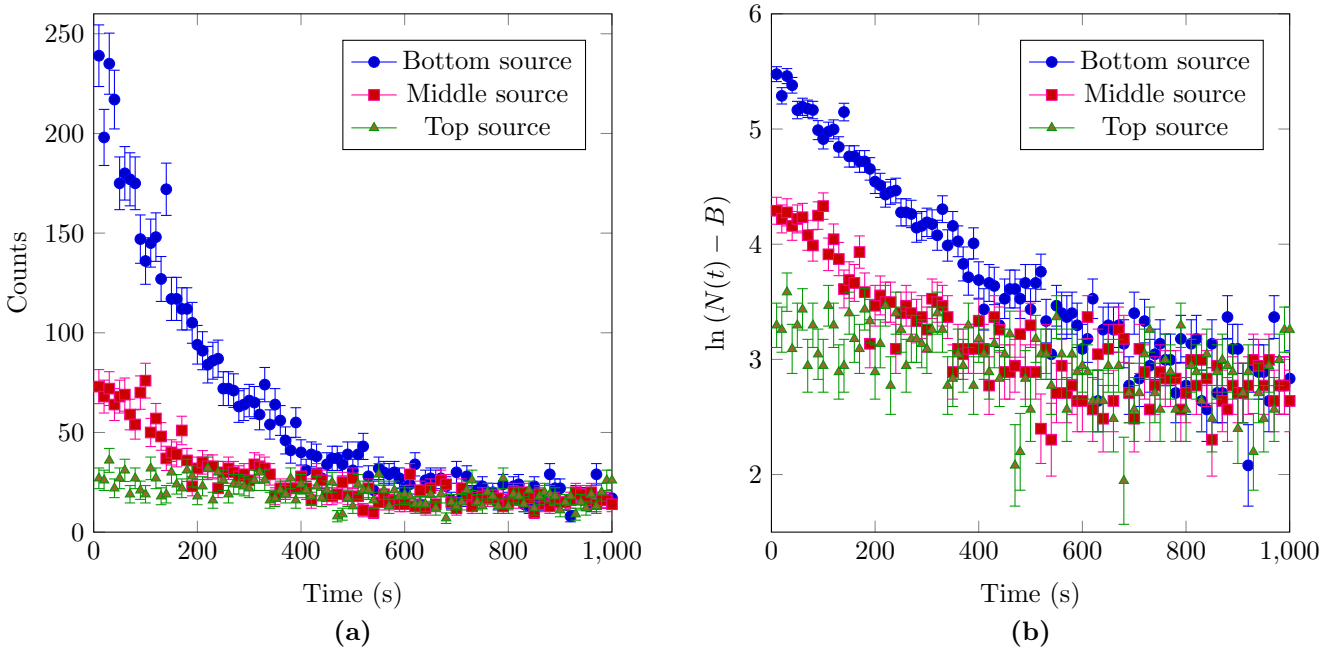

Figure 3: Plots showing the decay of the 1771 keV energy peak produced by ^{28}Al. Figure 3a represents the exponential decay curve of the isotope, as depicted by Equation 2, while Figure 3b depicts the linearized version of the data using Equation 4.

The plots in Figure 3 show a clear and substantial decrease in the slope as the source moves further away from the neutron emitter. Of particular note is the fact that the curves of the bottom and middle source in Figure 3b are parallel to each other, which indicates that the half life could still be estimated from this position. However, there is too little data to go off on with regards to the top source, which was placed the furthest away from the neutron emitter. In fact, it is almost constant with respect to the background, suggesting that the ^{28}Al has already decayed substantially by the time the measurements were taken.

5 Conclusion

The report highlights the different isotopes that are created following the neutron activation from an ^{241}Am-Be source on samples of ^{27}Al, of which three were found by cross-referencing the peak energy emission and half life with that of probable corresponding isotopes from literature. One of the effects that distance from the neutron emitter has on the ^{27}Al samples was found to be a decrease in the overall intensity of the energies related to the isotopes created by the activation of the sample. Furthermore, it revealed an isotope that is independent from the neutron activation of ^{27}Al, which might have been overlooked as it appears to coincide with the Compton edge of ^{28}Al.

6 References

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