

Low Background Counting Studies of the Cosmogenic



Activation of Titanium

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Dark Matter and Low Background Counting

Dark matter comprises roughly 85% of the total matter in the universe and is one of the biggest mysteries in modern physics.

- Does not interact with photons through electromagnetic forces.
- Does interact with ordinary matter through gravitational and weak forces.
- Has never been directly detected before

The world's leading dark matter experiment, LUX-ZEPLIN (LZ), is located at the Sanford Underground Research Facility (SURF). Its goal is to prove that dark matter is a Weakly Interacting Massive Particle (WIMP) [1]. By using a dual-phase xenon Time Projection Chamber (TPC), shown in Figure 1, LZ aims to detect low energy nuclear recoil signals from WIMPs [1]. The detector is located 4850 ft below ground shielding it from cosmic rays to limit other sources of interference with the detector.

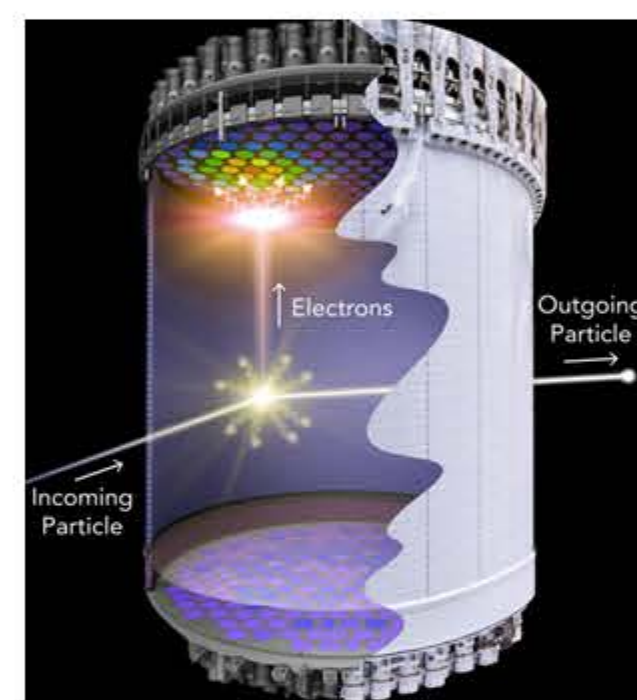


Figure 1. This is the TPC within LZ. Filled with purified liquid xenon, this is where the incoming WIMP will recoil from the nuclei of the xenon and emit light that the Photo Multiplier Tubes will detect [2].

The Black Hills Underground Campus (BHUC) at SURF, uses six High Purity Germanium (HPGe) detectors to screen materials and determine the level of radiation they give off in a process known as low background counting [1]. LZ is extremely sensitive so a small amount of background radiation could interfere with dark matter signals. HPGe detectors count the number of times and how much energy gamma rays have when they hit the germanium crystal in the detector.

Cosmogenic Activation of Titanium

The cryostat vessel within LZ is made of titanium, and isotopes of scandium are sociogenically activated when titanium undergoes neutron capture. Scandium will then β -decay back into titanium, shown in Figure 2. (^{46}Sc $\tau_{1/2} = 83.8$ days, ^{47}Sc $\tau_{1/2} = 3.35$ days).

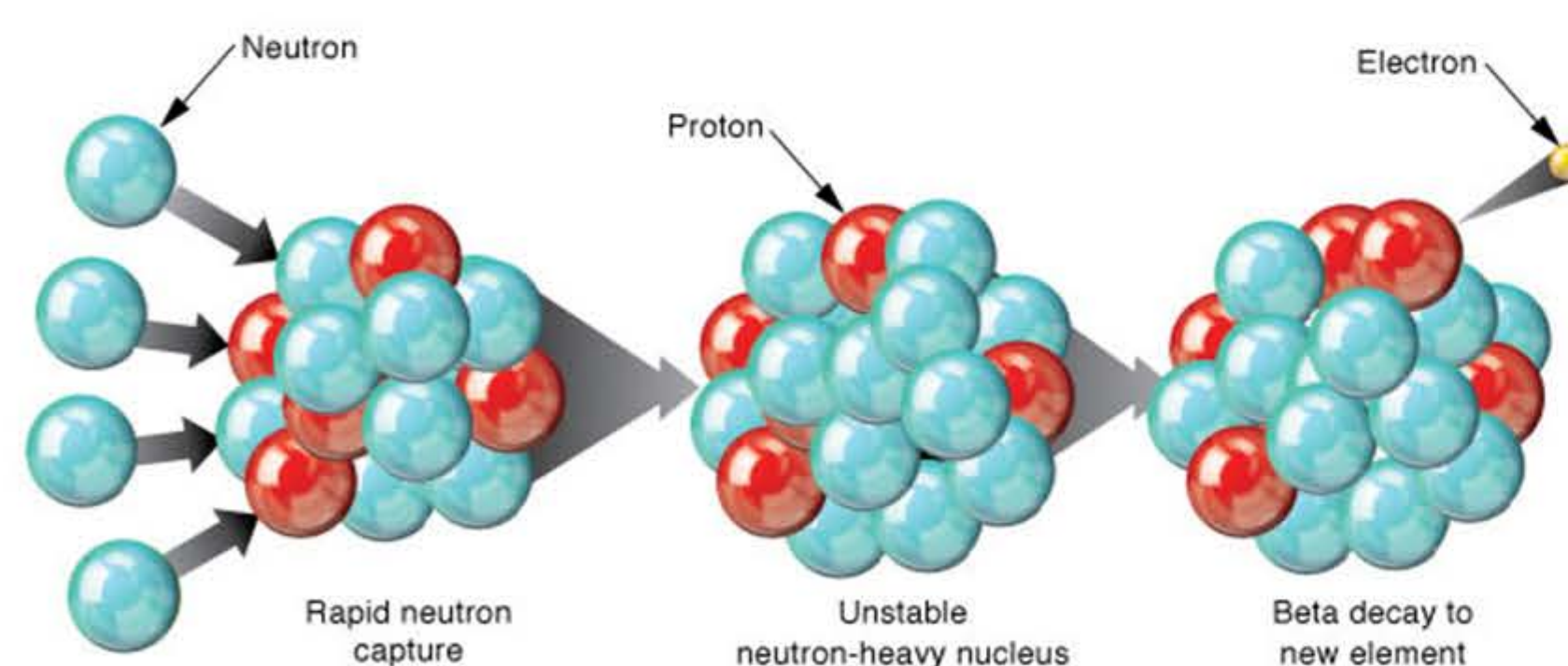


Figure 2. This is an example of neutron capture followed by a β -decay [3].

Titanium was chosen to construct the cryostat vessel because it has a high strength-to-weight ratio, is resistant to corrosion, and has less radioisotopes that could be activated than stainless steel or copper [4]. XLZD, the next generation dark matter experiment [5], also plans to use titanium for the construction of the cryostat vessel for the same reasons. Samples of titanium from LZ were brought above ground 10 years ago and the goal of this experiment is to establish a baseline for scandium in the titanium samples acquired.

Gamma Ray Spectroscopy

Radioactive decays follow a chain of transformations from parent to daughter isotopes, shown in Figure 3. Many materials contain naturally occurring radioactive nuclides, the most common being ^{238}U , ^{235}U , ^{232}Th . Their progeny emit various radioactive species through their decay, eventually leading to stable isotopes of lead. Each time a decay occurs, a characteristic gamma ray with a specific energy is emitted. By analyzing the specific energy given off by each gamma ray, we can identify which radioactive isotope was present.

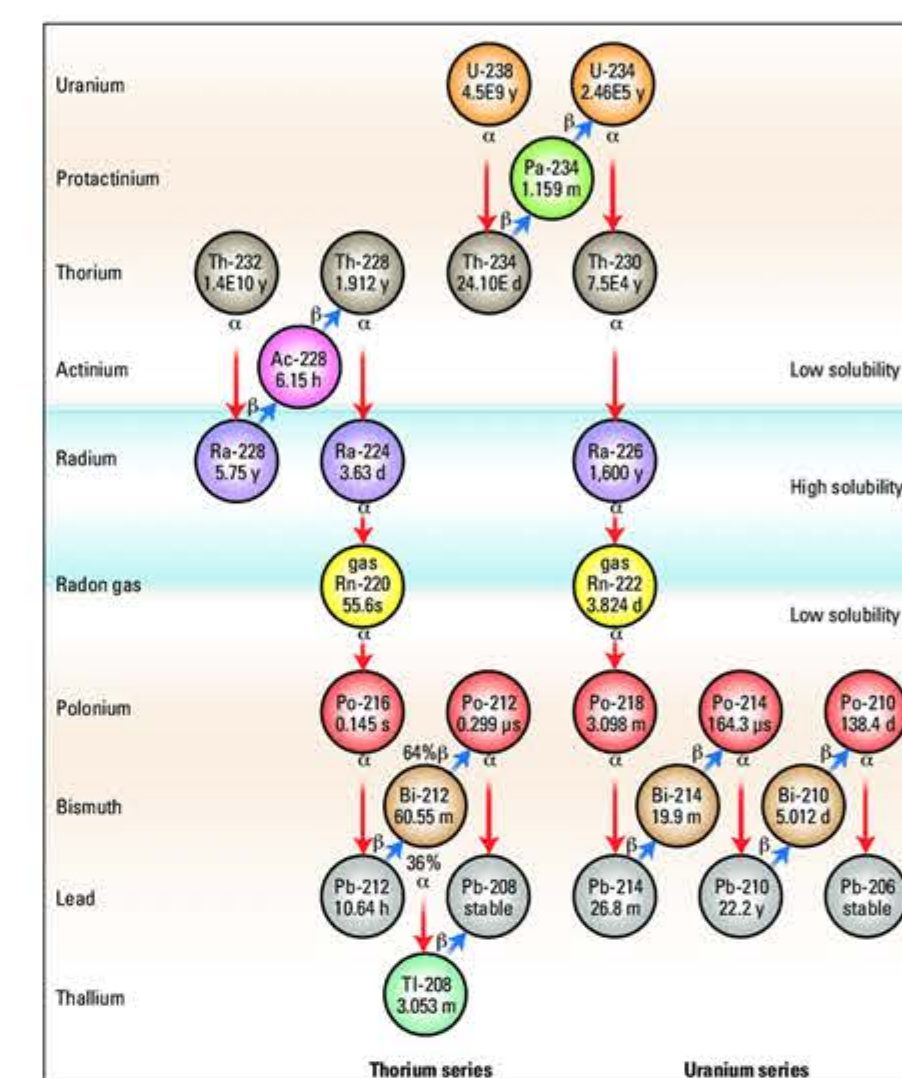


Figure 3. Decay chains for ^{238}U and ^{232}Th [6].

Counting Titanium

The titanium samples had been kept above ground at the Black Hills State University (BHSU) for 10 years. The titanium slabs were placed in mylar bags and ammo cans before being brought underground to prevent contamination from radon in dust from the tunnels. Once underground, the titanium was cleaned with isopropyl alcohol to remove any dust present. After being cleaned, the titanium was placed into Morgan, shown in Figure 4, an Ortec [7] 85% relative efficiency p-type detector [8].



Figure 4. Researcher Archer Sagaskie loading Titanium into MORGAN.

After two weeks of data collection, an issue occurred which made 5 days worth of the data unusable. The nitrogen purging system functioned incorrectly which allowed radon into the detector, causing the count rate to increase steadily, shown in Figure 5.

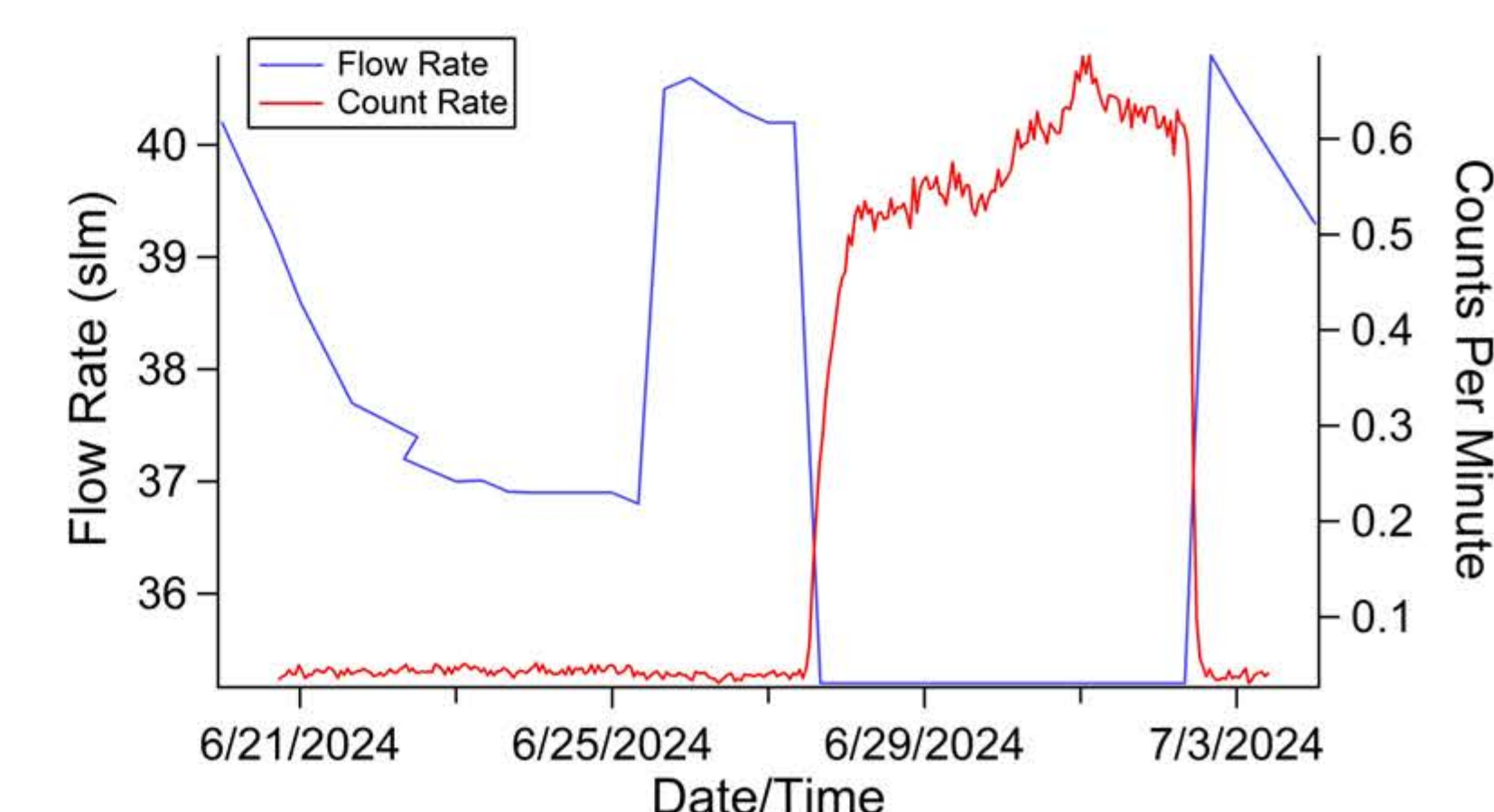


Figure 5. Graph of flow rate vs time and counts per minute vs time.

Removing the affected data was necessary to have meaningful results. However, a shorter live time reduced the number of counts from some radioisotopes.

Data Analysis

After analyzing the data through Peakeasy [9], it was clear that radioisotopes of ^{46}Sc and ^{47}Sc are present when compared to the background, shown in Figure 6. ^{46}Sc has two distinct energy levels, shown in Figure 7, at 889 keV and 1121 keV but ^{47}Sc only one at 159 keV.

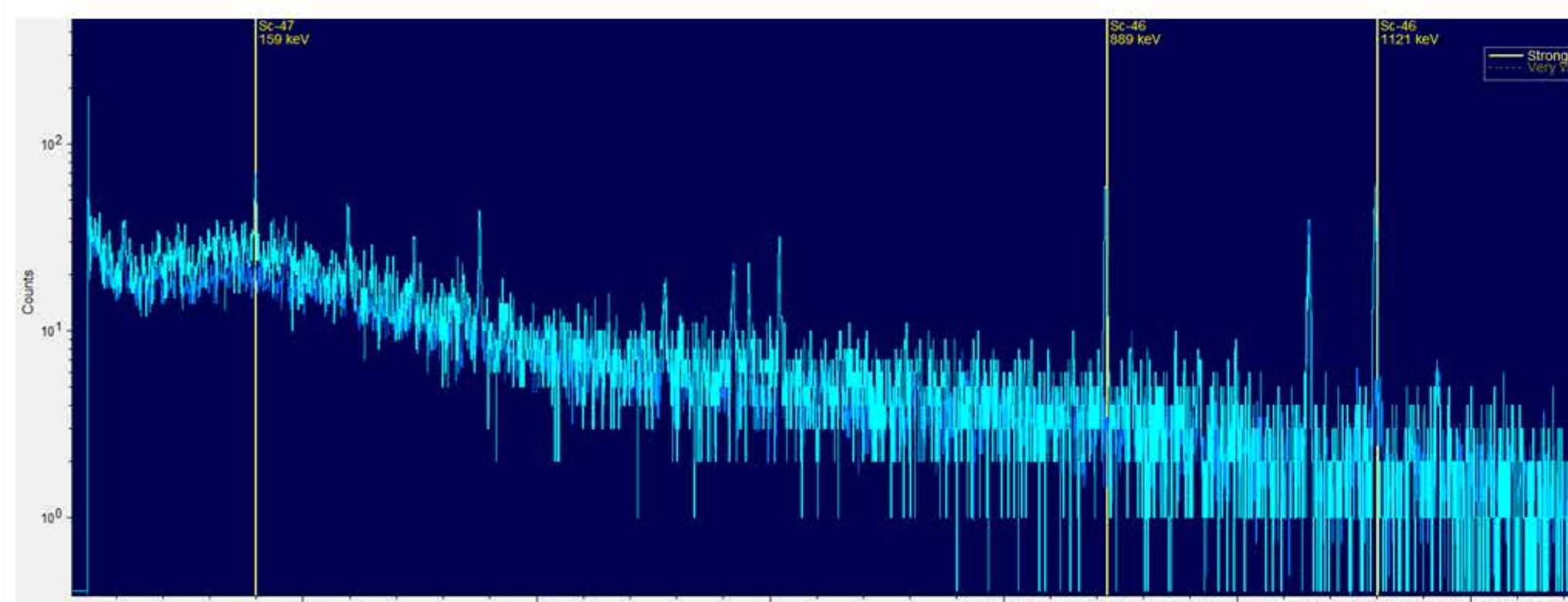


Figure 6. This is the spectra produced by Peakeasy for the titanium sample. Each highlighted peak is an isotope of scandium.

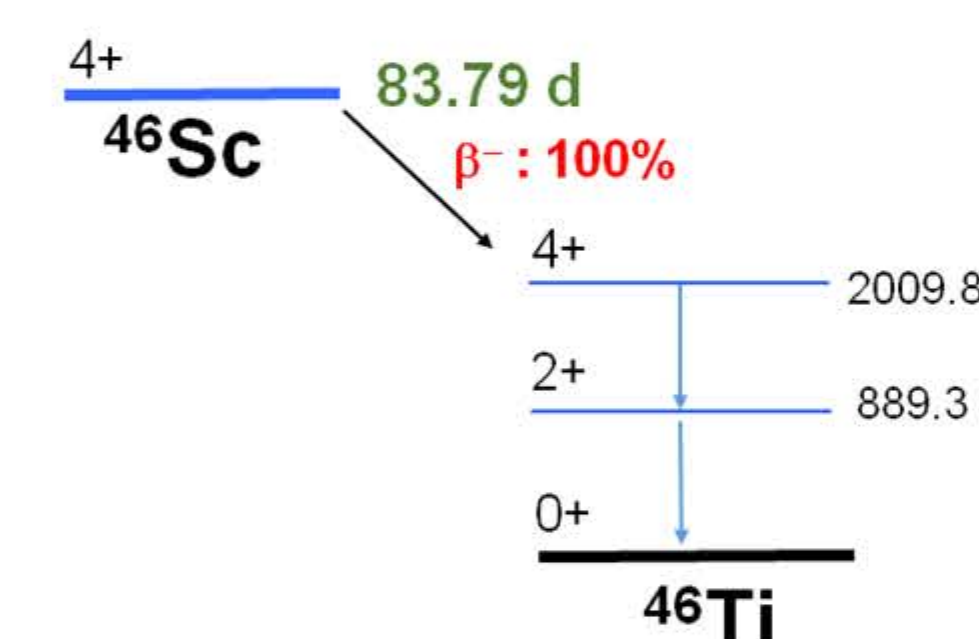


Figure 7. This shows the distinct energy levels for ^{46}Sc [10].

To calculate the concentration of isotopes of scandium present in the sample, an approximation was made for the full energy peak efficiency of scandium. Efficiencies for other isotopes are well known because of a calibration standard known as Table Mountain Latite (TML). By plotting the efficiencies vs energy, shown in Figure 8, we estimated the efficiency for each isotope of scandium at their respective energies. By using the equation in Figure 9, the concentration of both isotopes of scandium was found.

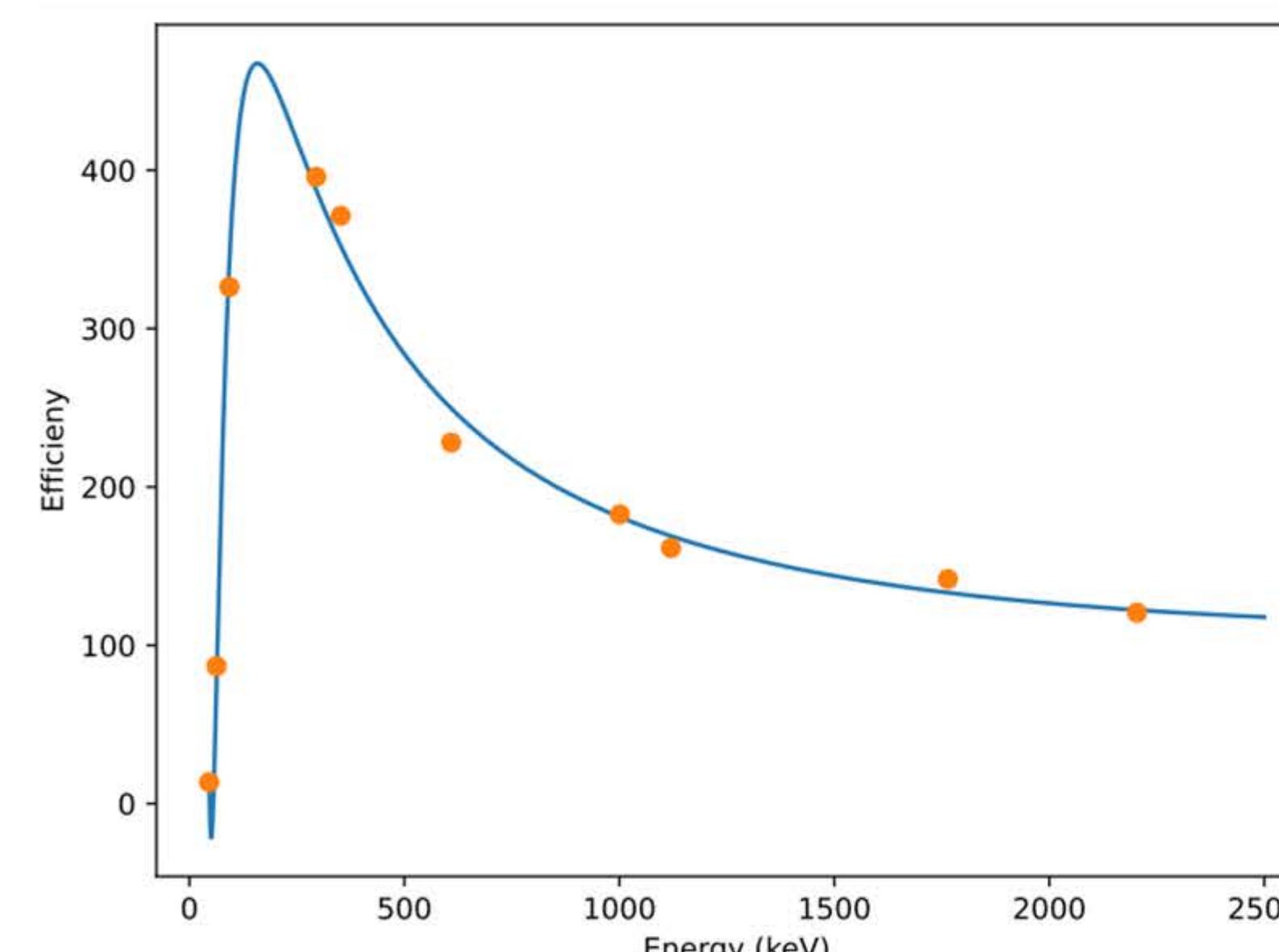


Figure 8. This is a graph of the early and late uranium Chain efficiencies from the known TML sample. This was used to determine the efficiency of scandium

$$C = \frac{N_{\text{peak}}}{\epsilon_{\text{peak}} M_{\text{sample}} P_{\gamma} LT}$$

Figure 9. The equation used to determine concentration. N_{peak} is the background-adjusted net peak area, ϵ_{peak} is the full energy peak efficiency, M_{sample} is the mass of the in g, P_{γ} is the emission probability, LT is the live time of the sample run in minutes [11].

Results

A baseline for the concentration of scandium in this sample of titanium was established.

- The concentrations of ^{46}Sc and ^{47}Sc are listed in Table 1.
- Over time, these concentrations will decrease because scandium will beta decay into ^{46}Ti and ^{47}Ti .

Table 1. The concentrations of ^{46}Sc and ^{47}Sc are listed above in parts per billion and millibecquerel per kilogram with their associated errors.

Source	ppb	mBq/kg
Sc-46	0.484 (0.080)	606 (100)
Sc-47	0.174 (0.051)	5335 (63)

Future Work

To verify the decay rate of scandium in titanium, these steps need to happen:

- Analyze the same titanium every few months.
- Determine the concentration of scandium at that time and compare this to the baseline.
- Compare this to the known half lives of the isotopes of scandium present.

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