Search for new isotopes ^{220}U and ^{224}Pu and Exploration of the Mass Surface Near N = 126

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Introduction and Motivation

- The aim of the experiment was to populate and measure the lifetime of two undiscovered nuclei, ^{224}Pu and ^{220}U.

- This was done by populating the nucleus ^{228}Pu and observing the subsequent alpha decays from the 4n channel.

- Measurement of the decay properties of these nuclei will give information on the structure of these nuclei and test the robustness of the shell closure at N = 126.

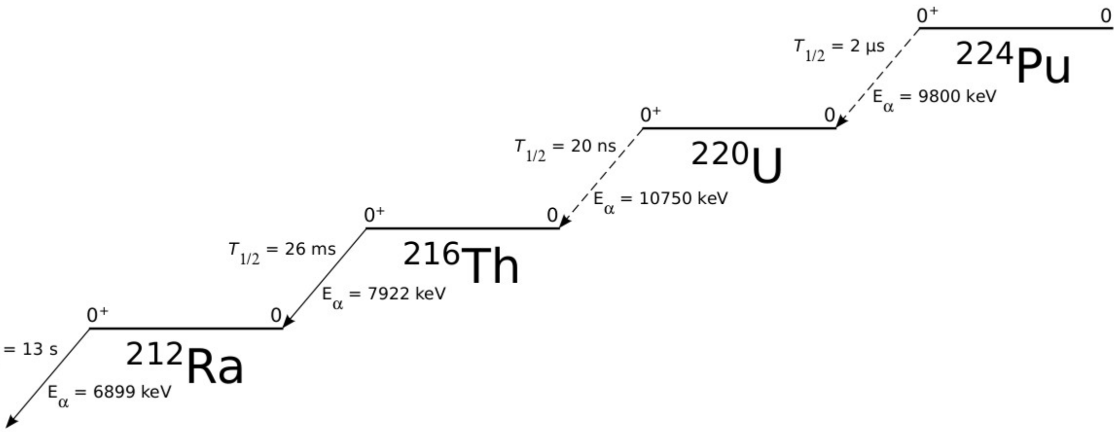
	221Pu	222Pu	223Pu	224Pu	225Pu
219Np	220Np	221Np	222Np	223Np	224Np
218U 0.51 ms α = 100.00%	219U 42 μs α = 100.00%	220U α ?	221U 0.66 μs α ≈ 100.00%	222U 4.7 μs α ≈ 100.00%	223U 18 μs α = 100.00% ε = 0.20%
217Pa 3.6 ms α = 100.00%	218Pa 113 μs α = 100.00%	219Pa 53 ns α = 100.00%	220Pa 0.78 μs α = 100.00% ε = 3.0E-7%	221Pa 5.9 μs α = 100.00%	222Pa 2.9 ms α = 100.00%
216Th 26.0 ms α = 100.00% ε ≈ 0.01%	217Th 0.241 ms α = 100.00%	218Th 117 ns α = 100.00%	219Th 1.05 μs α = 100.00%	220Th 9.7 μs α = 100.00% ε = 2.0E-7%	221Th 1.68 ms α = 100.00%
215Ac 0.17 s α = 99.91% ε = 0.09%	216Ac 440 μs α = 100.00%	217Ac 69 ns α = 100.00% ε ≤ 2.00%	218Ac 1.08 μs α = 100.00%	219Ac 11.8 μs α = 100.00%	220Ac 26.4 ms α = 100.00% ε = 5.0E-4%

Introduction and Motivation

- Alpha decay is a binary emission process in which a nucleus emits two protons and two neutrons, also known as an α particle or a Helium-4 nucleus.

- By linking the decay of ^{224}Pu and ^{220}U with ^{216}Th, the masses of the unknown nuclei can be measured directly.

$$^{A}_{Z}X_{N} \longrightarrow \, ^{A-4}_{Z-2}X'_{N-2} + \alpha.$$



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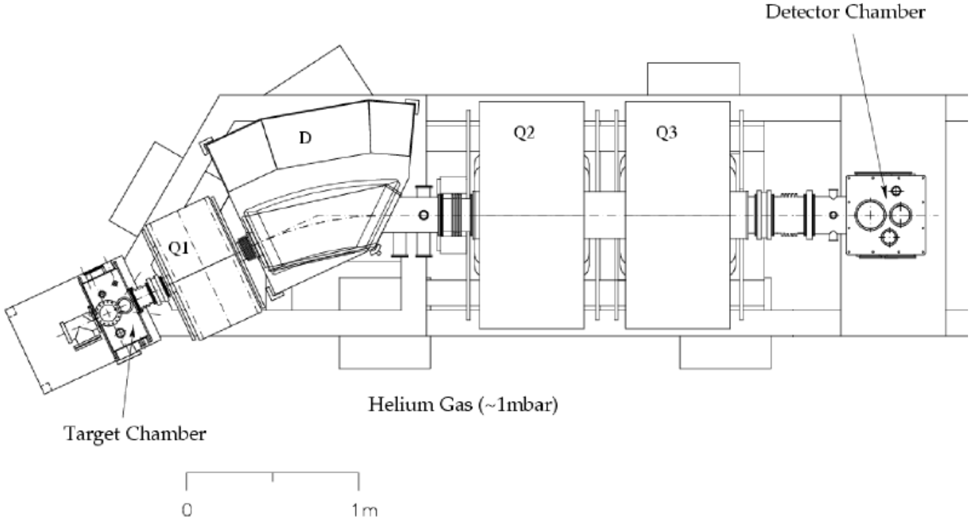
Experimental Set Up

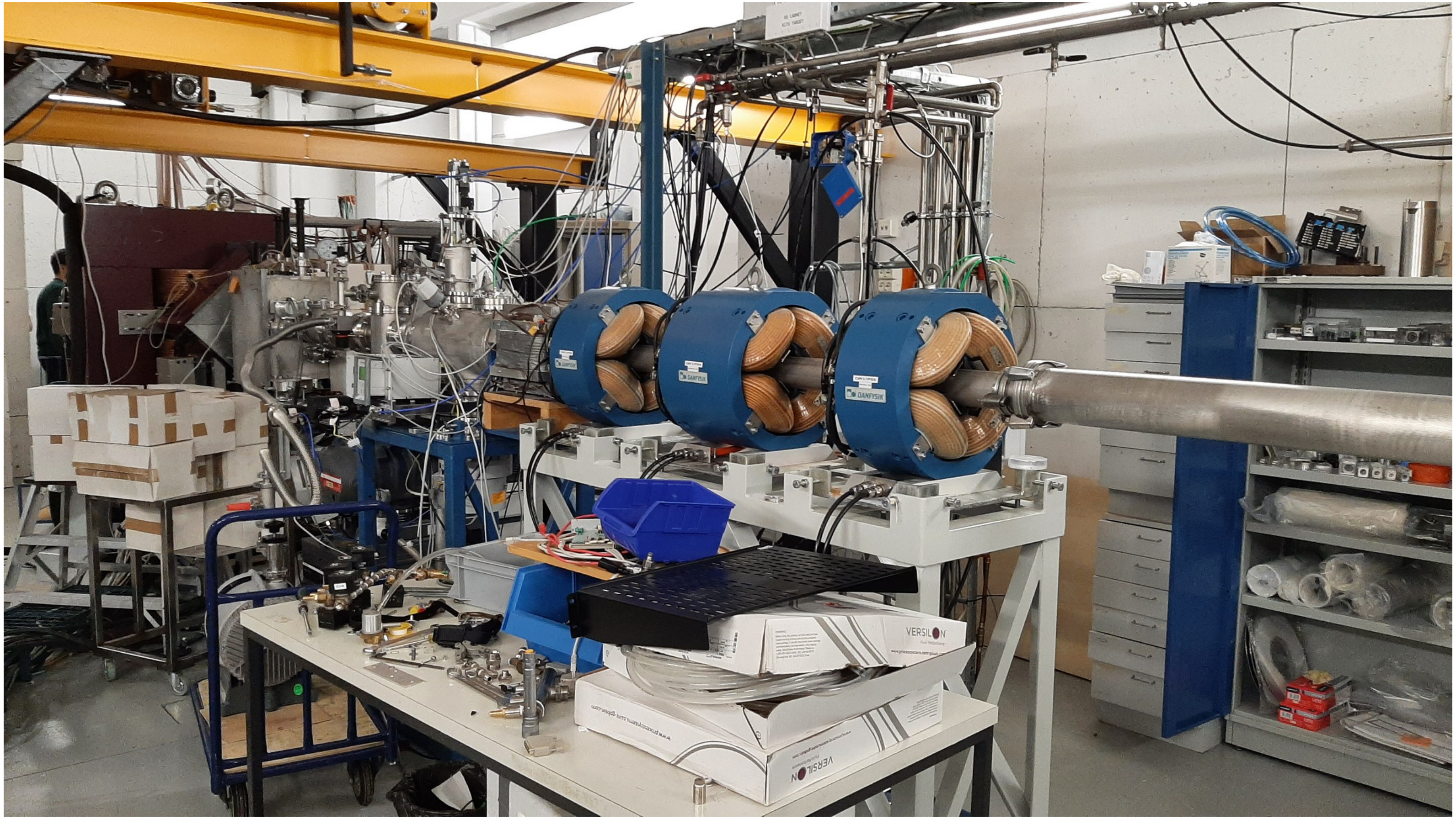
- This experiment was conducted at the University of Jyvaskyla In Finland and made use of the K130 cyclotron to create a ^{32}S beam which was the incident on a ^{196}Pt target as part of a fusion evaporation reaction.

- The fusion products were then sent to the focal plane of the Recoil Ion Transport Unit (RITU) separator. At the focal plane the products were implanted into a double-sided silicon strip detector (DSSD) which was surrounded by silicon PIN diode detectors.

$$^{32}S + ^{196}Pt \longrightarrow ^{228}Pu^* \longrightarrow ^{224}Pu + 4n.$$



Beam Line



RITU

Recoil Decay Tagging Method

- The first implantation in the DSSD is labelled as a recoil and any subsequent implantations in the same pixel are labelled a decay if the meet the necessary criteria.

- Once a nucleus is implanted in the DSSD (e.g. ^{224}Pu) there are four possible scenarios:
  1) ^{224}Pu, ^{220}U and ^{216}Th are detected in the same pixel with their full energy.
- 2) The full energy of ^{220}U and ^{216}Th are detected and the ^{224}Pu α particle escapes the DSSD.
  3) Similar to 2) but the ^{220}U alpha particle escapes with its full energy.
- 4) Only the full energy of the ^{216}Th α particle is detected and the others escape.

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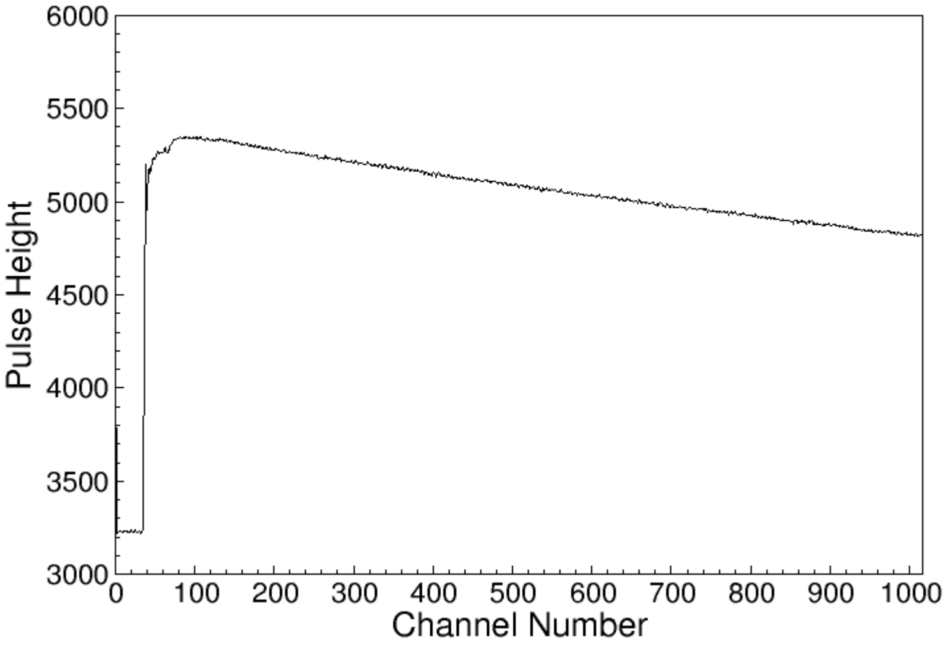
Trace Analysis

- The raw signals of the events in the DSSD were taken from the pre-amplifier and are similar to what would be seen on an oscilloscope.
- These are known as traces and their pulse height is proportional to the energy of the implantation.
- An example of one of these traces can be seen in the figure, where each channel number is equal to 10 ns.

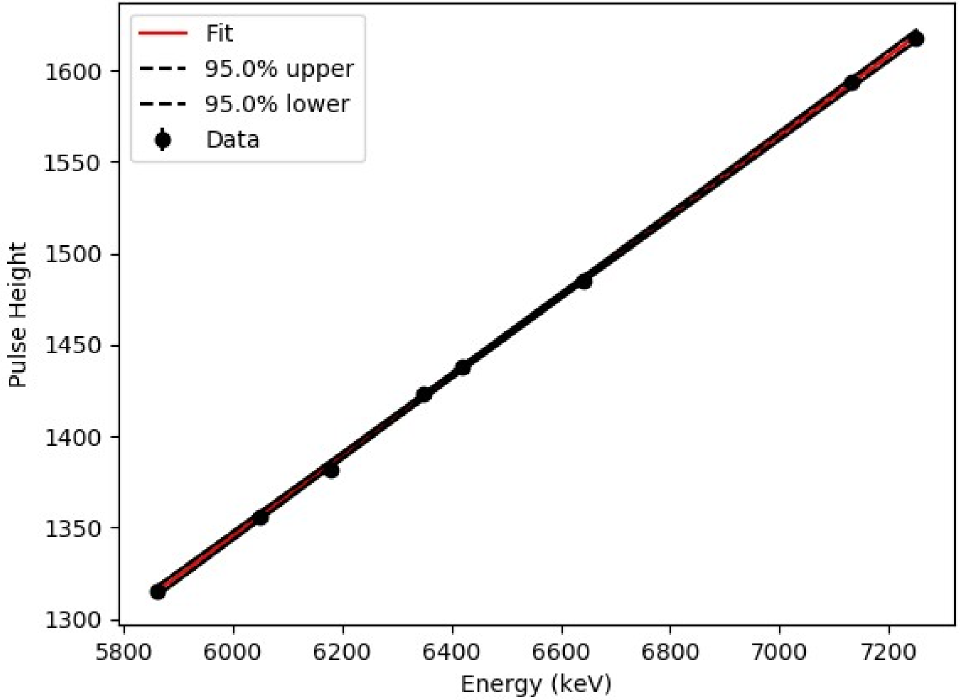


Calibration of DSSD

- Using select calibration traces and the activities of known decays it was possible to preform a calibration of the DSSD. This calibration can be seen in the figure.

- This allowed for the energy of the each trace to be calculated using the equation of the calibration line:

$$y = 0.22x + 31.77.$$



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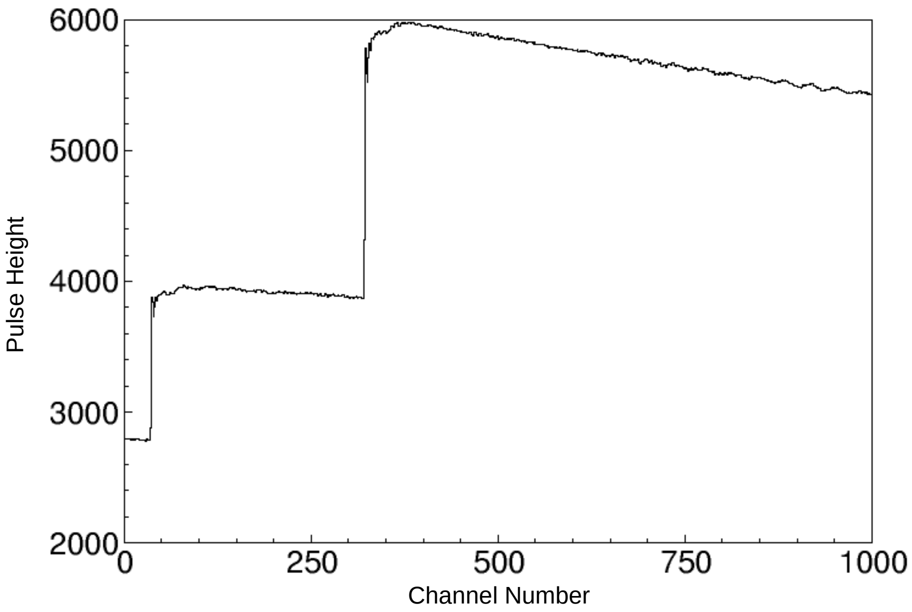
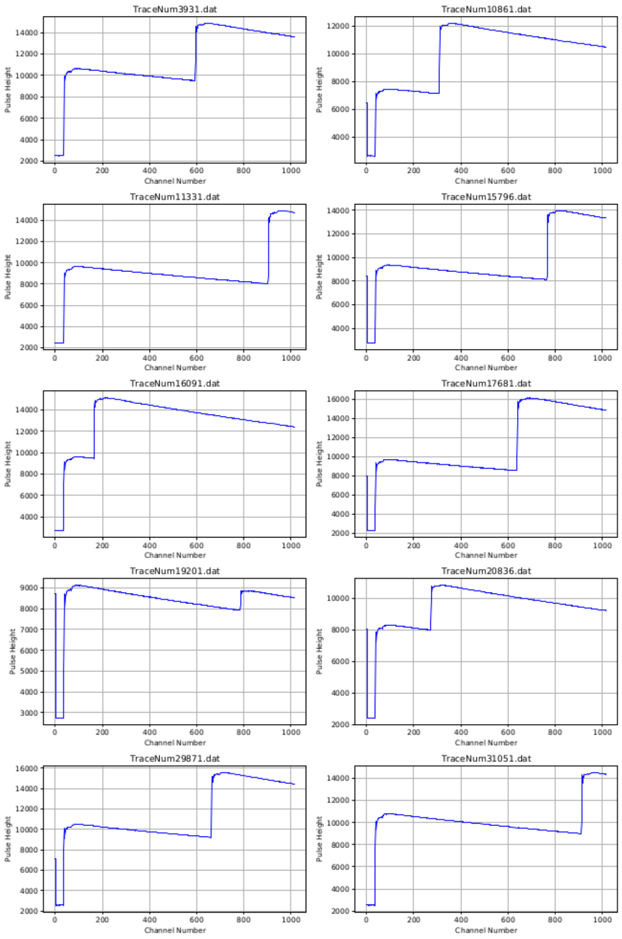
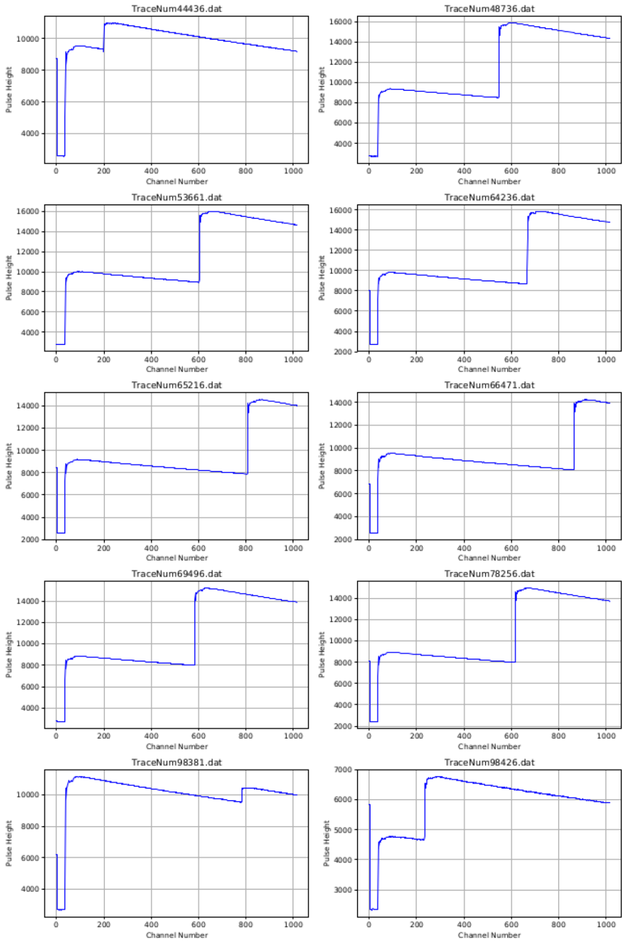
Trace Analysis

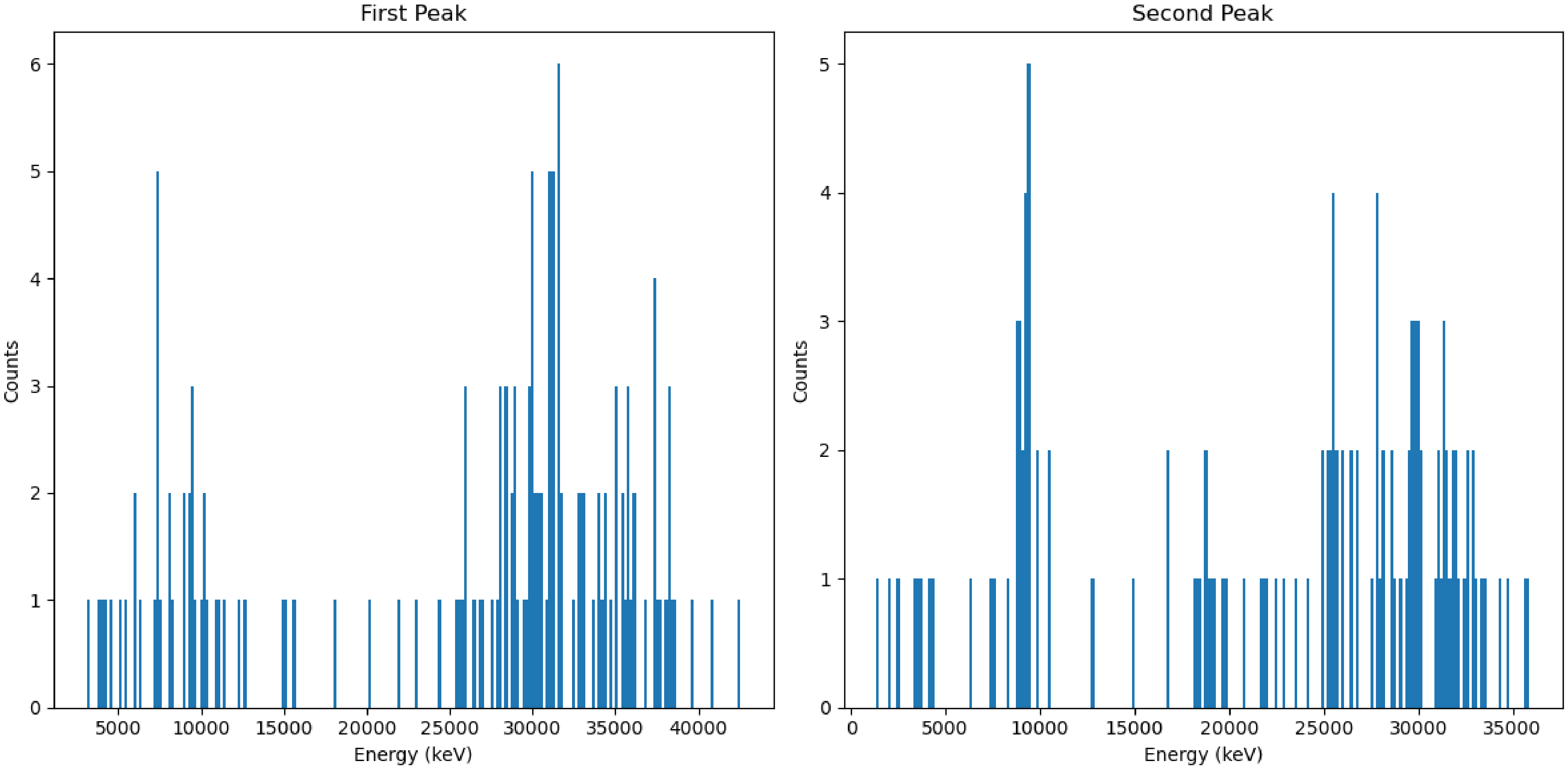
- Due to the short life times of the nuclei created in this experiment it is possible for more than one event to be recorded within a trace.
- These “double traces” are possible candidates for the desired unknown nuclei. An example of one of these traces can be seen in the opposite figure.
- The calibrated pulse heights of each peak were plotted in a histogram.



Trace Analysis



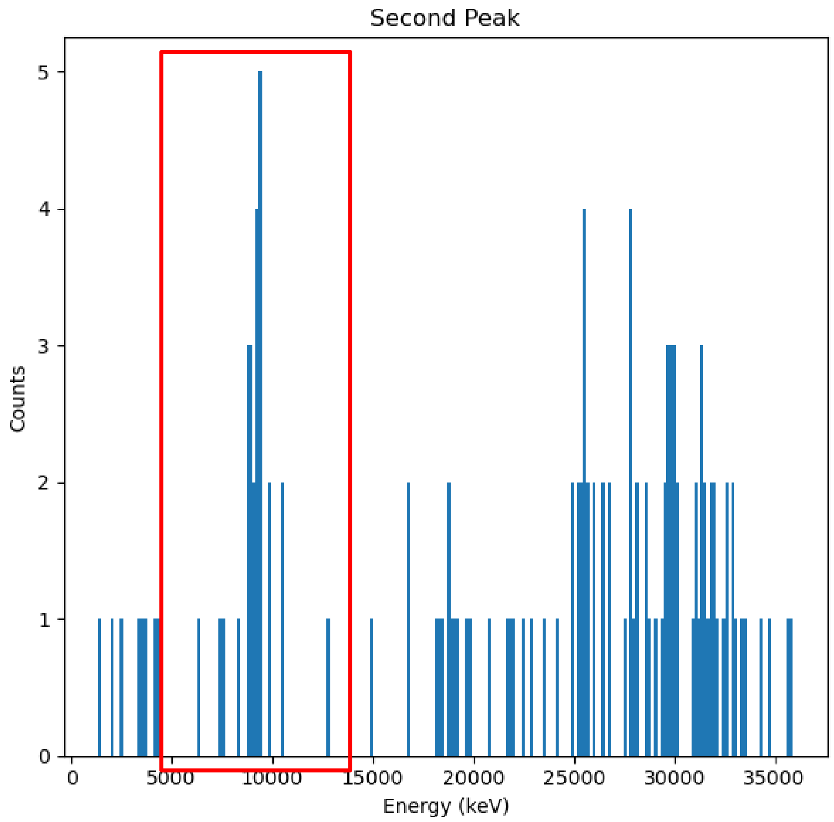




First Peak
Counts
Energy (keV)
0
1
2
3
4
5
6
5000
10000
15000
20000
25000
30000
35000
40000
Second Peak
Counts
Energy (keV)
0
1
2
3
4
5
0
5000
10000
15000
20000
25000
30000
35000

Trace Analysis

- The first histogram is a plot of the energies of the implantations and the second histogram is a plot of the energies either a subsequent decay or an escaped particle.
- It can be seen that for the second pulses there is a clear peak at 9240 keV. Some of these counts are consistent with the α decay of ^{217}Th to ^{213}Ra.
- This could be evidence of ^{221}U also being populated.



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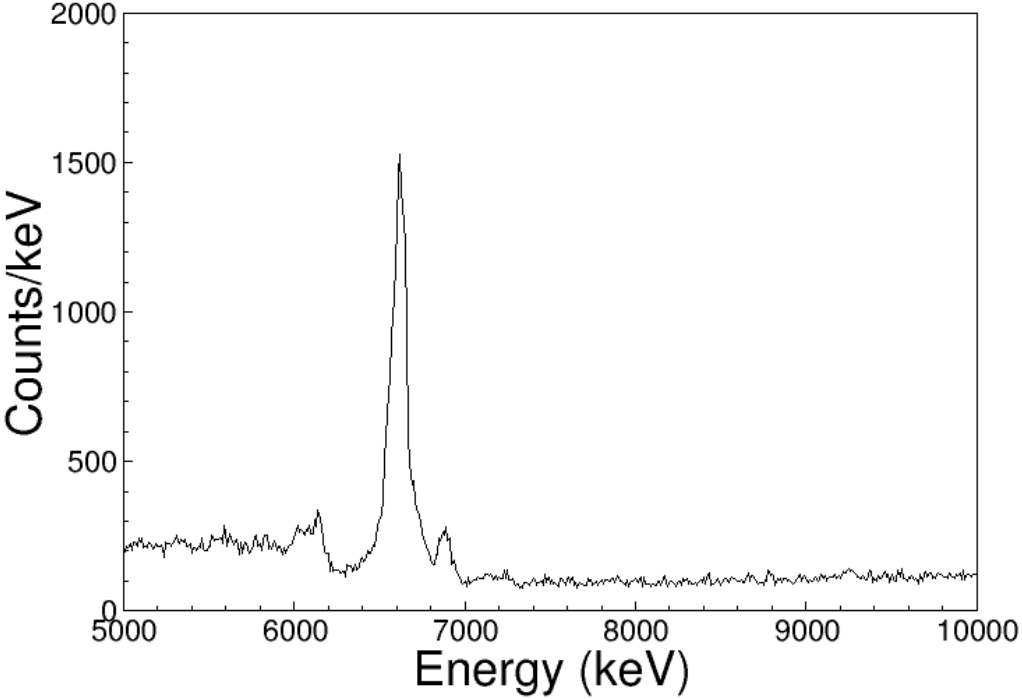
Alpha Spectra

- The raw spectra of events in the DSSD labelled as decays can be seen in the opposite figure.
- The main peak in this spectra is at 6620 keV.
- This activity is consistent with the α decay of ^{213}Ra to ^{209}Rn.



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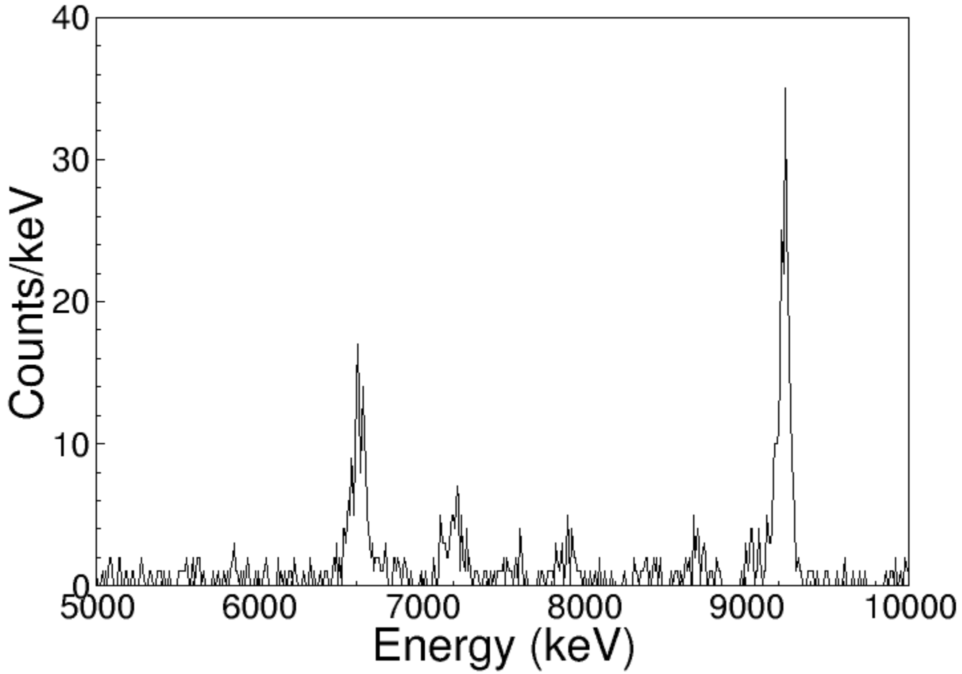
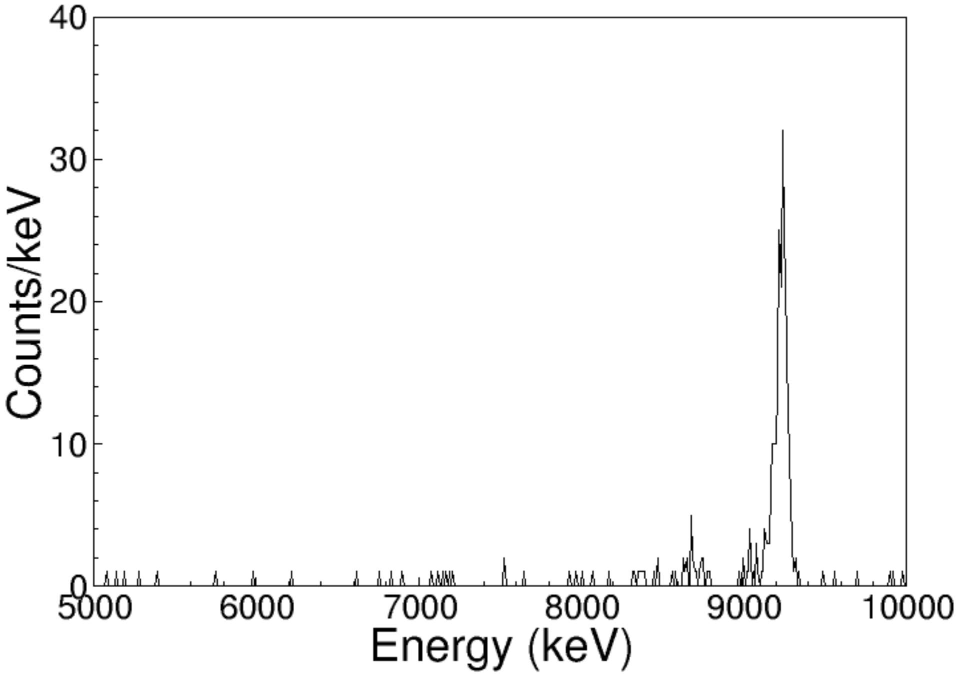
Alpha Spectra

- Below the same alpha spectra can be seen but with a condition imposed on the time between the recoil implantation and the subsequent decay.
- There is a clear peak at 9240 keV which is consistent with ^{217}Th.





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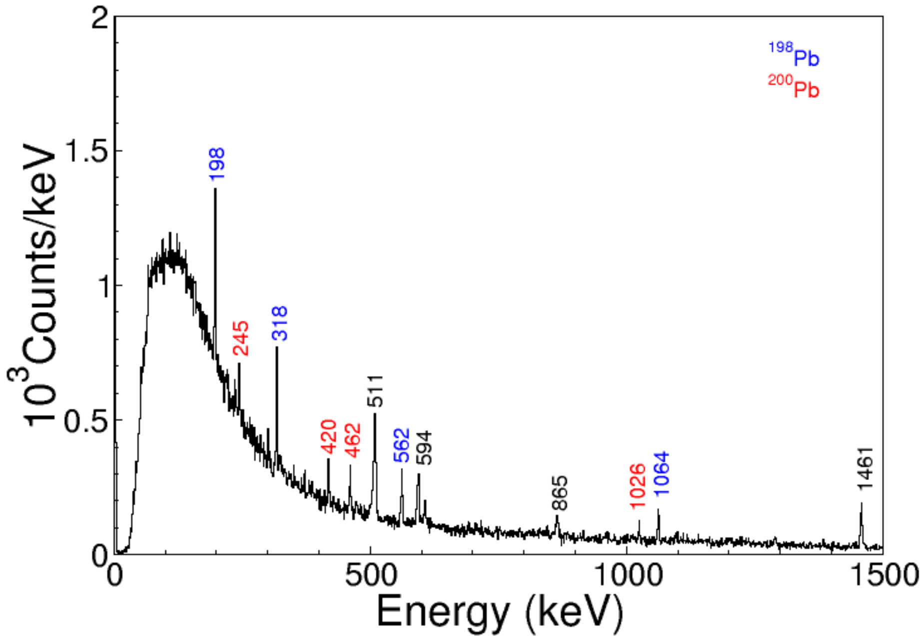
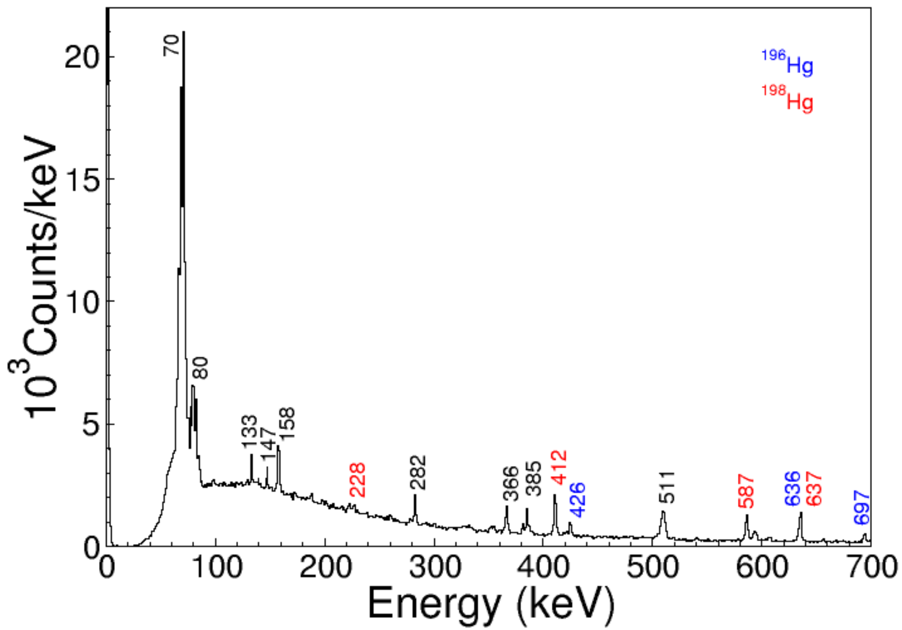
Gamma Spectra

- There were also high purity Germanium detectors positioned at the focal plane of RITU and below can be seen the spectra of the gamma rays in coincidence with recoils and decays.





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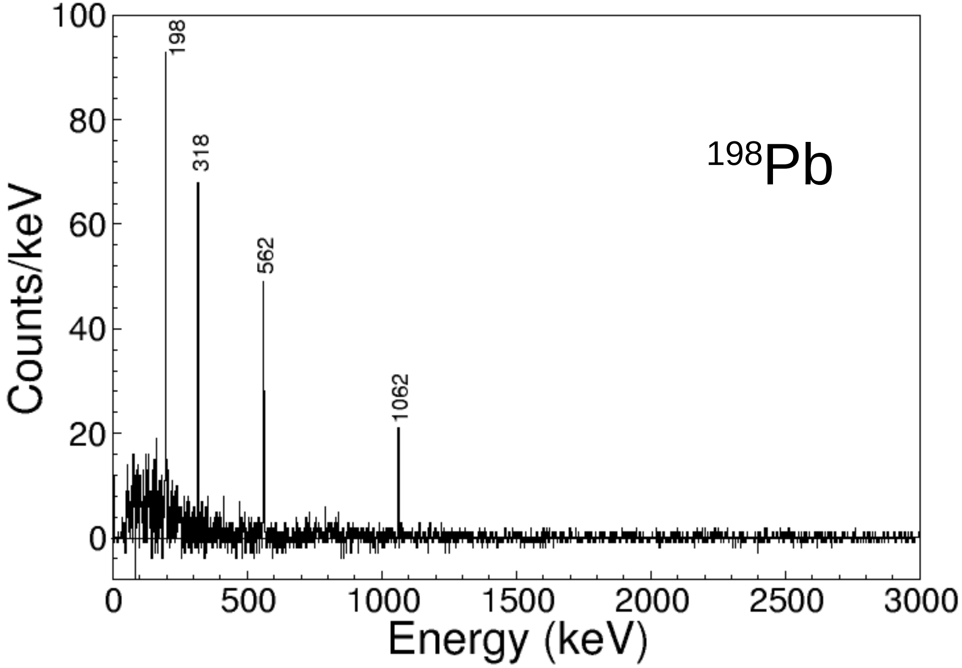
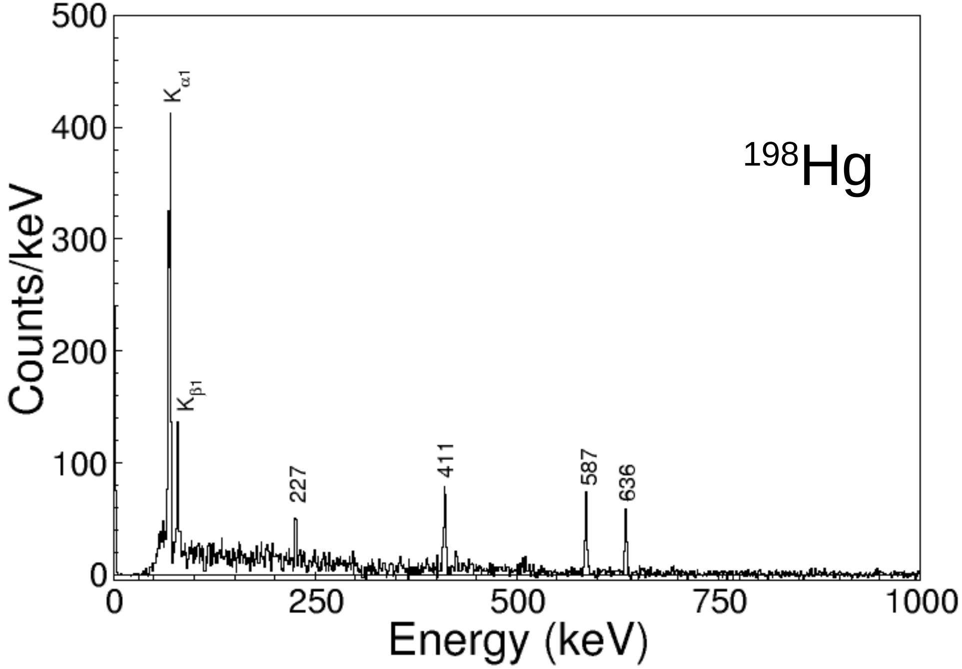
Gamma Coincidence Spectra

- Here the coincident gamma rays were summed together to produce the plots below.





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Discussion

- From the trace analysis there is evidence that ^{217}Th was populated.
- The raw alpha spectra also shows evidence of population of ^{217}Th and ^{213}Ra , which would be the daughter nucleus from α decay.
- Unfortunately there is no evidence of either ^{224}Pu or ^{220}U in either the trace analysis or the raw spectra.
- From the gamma ray spectroscopy it can be seen that most of the products are from nuclei neighbouring the target. This is evidence of multi-nucleon transfer occurring.

Future Work

The next steps in analysing this data set would be:

- Identify the remaining peaks in the alpha and gamma spectra.
- Look into the difference in counts between the alpha spectra and the traces in the 9240 keV peak.
- Determine the life times of the decays observed to verify what nuclei have been produced.

Acknowledgements

[1]D. O’Donnell, [1]B.S. Nara Singh, [4]P. Papadakis, [2]A. McCarter, [2]B. Alayed, [2]J. Ojala, [5]J. Khuyagbaatar, [6]P. Jones, [3]P. Greenlees, [3]M. Leino, [3]R. Julin, [3]J. Uusitalo , [3]T. Grahn, [3]J. Pakarinen, [3]P. Rahkila, [3]P. Ruotsalainen, [3]J. Sarén, [3]K. Auranen, [3]A. Briscoe, [3]A.Sison, [3]M. Luoma, [3]H. Joukainen, [3]H. Jutila, [3]J. Louko, [3]A. Plaza, [3]J. Romero, [3]G. Zimba, [3]V. Bogdanoff, [3]E. Uusikylä, [3]H. Kokkonen, [3]J. Ahokas.

1. University of the West of Scotland, United Kingdom
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