
Gamma Spectroscopy with Germanium Detectors

2015 REU Presentation - Tyler Takaro

Rare Event Searches



KATRIN



MAJORANA



ADMX

MAJORANA Background

- MAJORANA is a collaboration looking for $0\nu\beta\beta$ decay of ^{76}Ge
- To detect $0\nu\beta\beta$, must minimize backgrounds
- Important to know activity of hardware which might be used in experiment

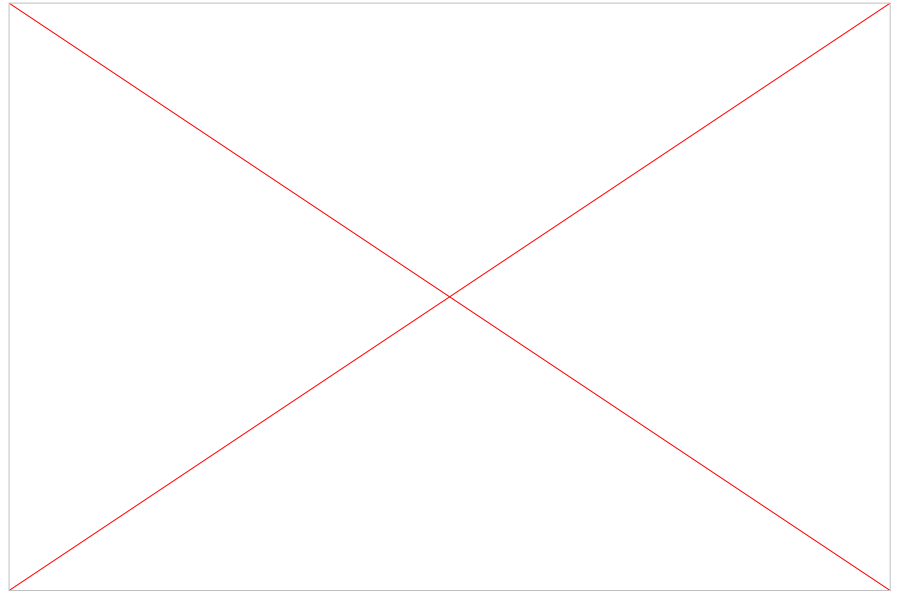


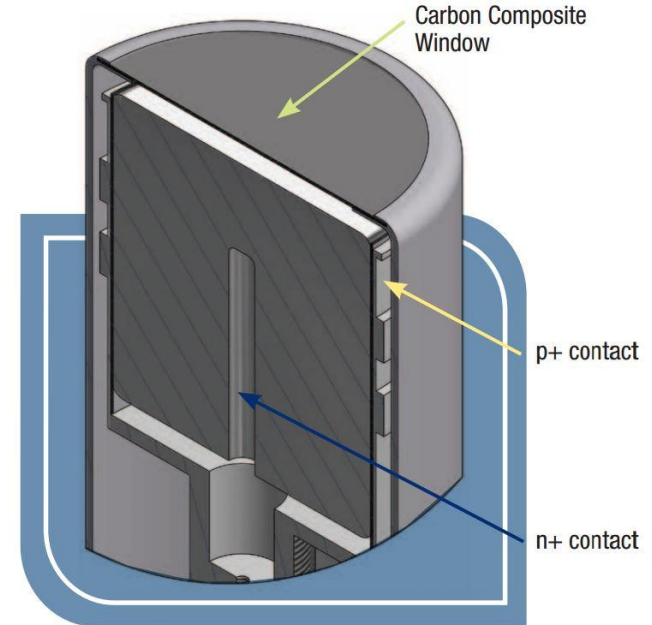
Image courtesy of MAJORANA: <http://www.npl.washington.edu/majorana/>

Natural radioactivity

- Uranium, Thorium, and Potassium are all present in our environment as natural radiation
- These show up in the background frequently, due to natural impurities in materials
- We measure these to determine the contribution of hardware to background by looking at the intensity of emission lines for ^{208}Tl , ^{214}Bi , and ^{40}K at 2614.5 keV, 1764.5 keV, and 1460.8 keV

C1: Germanium Detector

- C1 is a reverse electrode coaxial Ge detector
- Detects secondary gamma particles from beta decay
- Radiation damage decreased
energy resolution: 2.6 keV \rightarrow 5.8 keV FWHM



REGe Detector Configuration

Image courtesy of Canberra Industries:
<http://www.canberra.com/products/detectors/germanium-detectors.asp>

Using C1

- C1 previously had been having issues
- Initially saw microphonics when bringing C1 up to proper bias.
- Calibrated using 40K and background
 - Later calibrated using additional sources, and tuned for energy resolution



Image of C2, a similar detector to C1

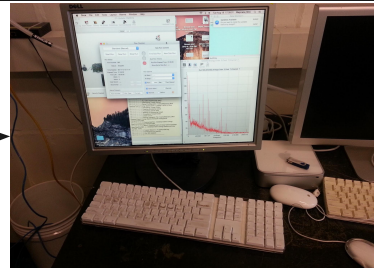
Experimental Setup



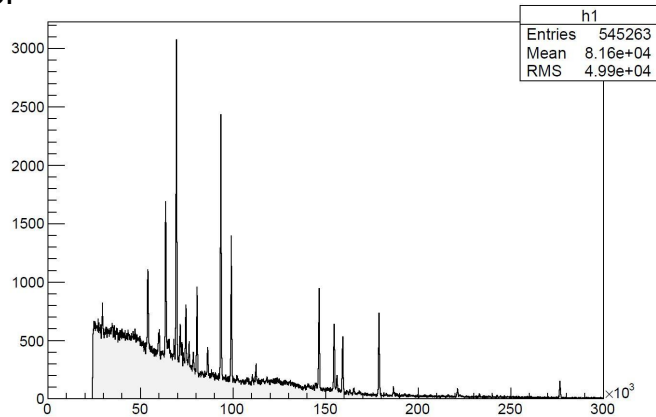
Detector



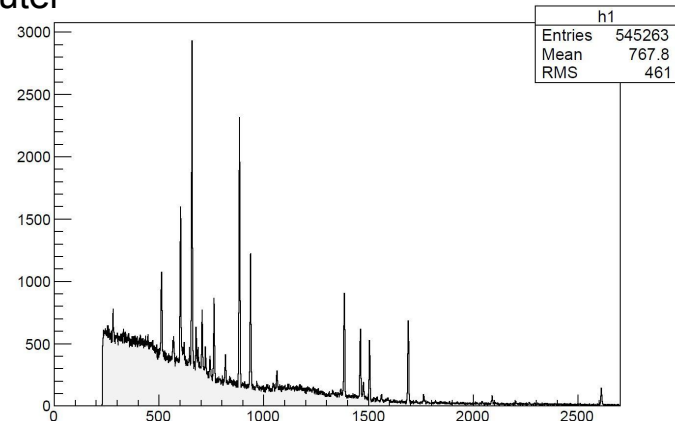
Digitizer and CPU



DAQ Computer



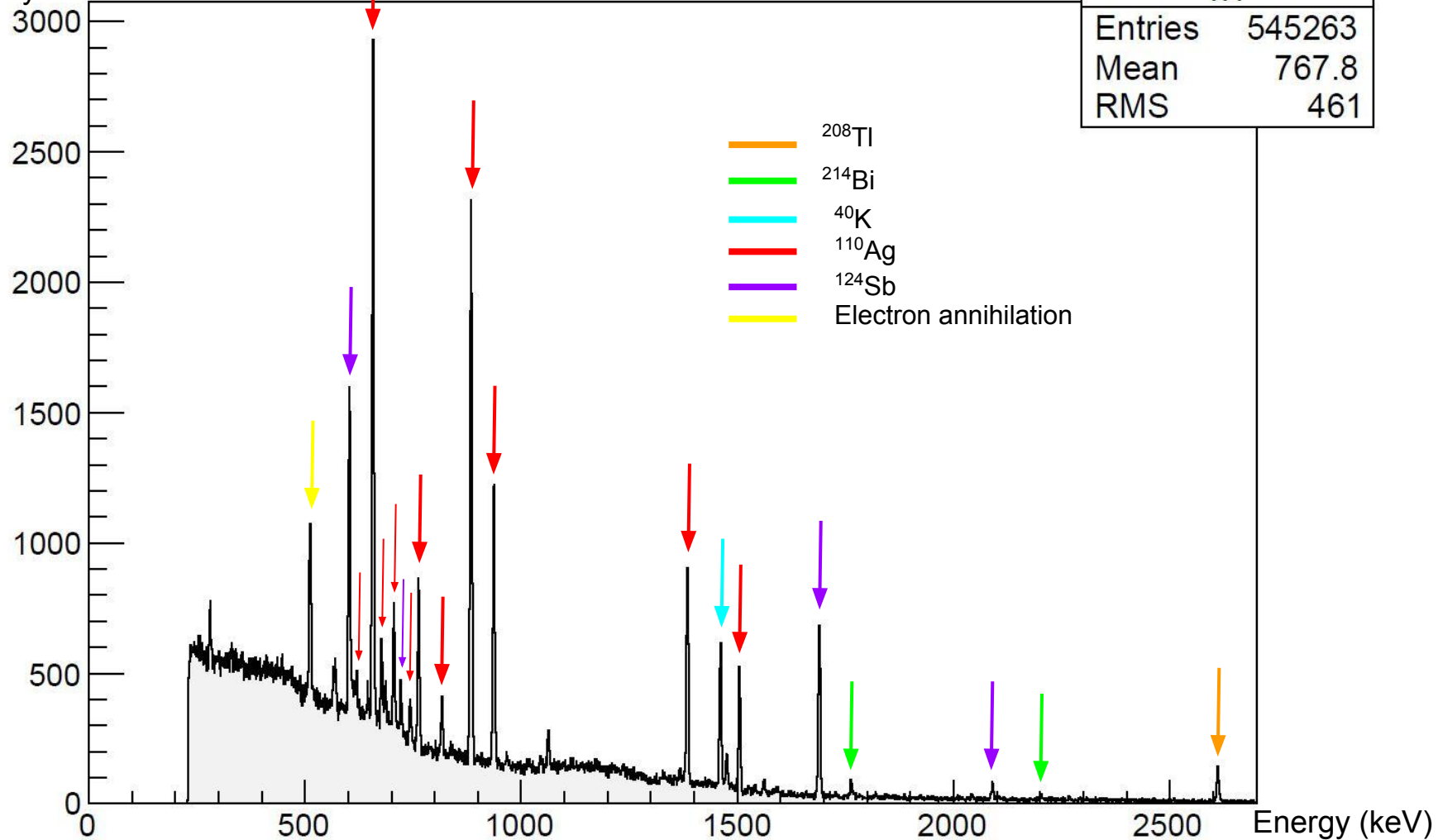
→
Calibration



Decays

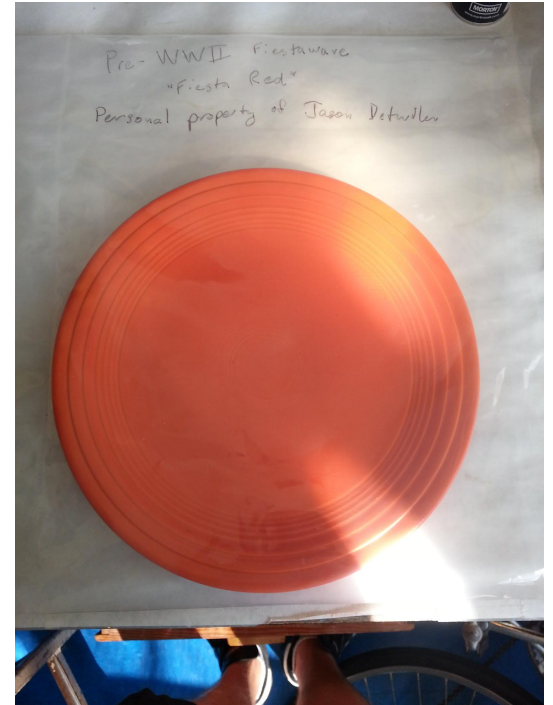
h1

Entries	545263
Mean	767.8
RMS	461



Uranium Fiestaware Plate

- Ceramic plate manufactured in the 1930s with Uranium glaze. It is estimated to have ~4.5 g natural Uranium.
- The decay spectrum has an unexpectedly prominent peak at ~1 MeV. This is consistent with ^{234m}Pa , but at a higher intensity than expected.

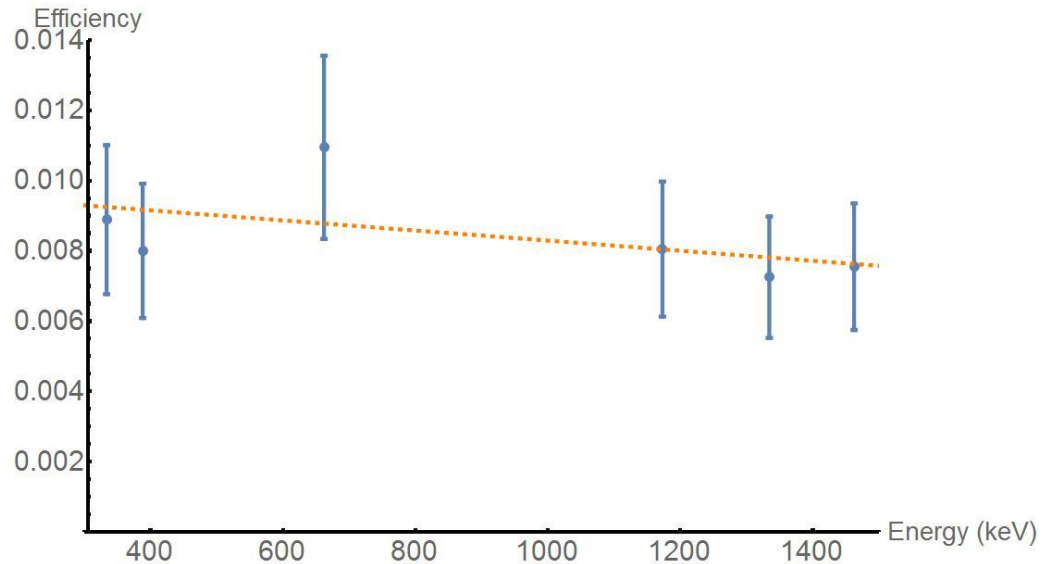


ORCA Troubles

- After a couple weeks of using the data acquisition software ORCA, it began to crash frequently, running for anywhere from 5 seconds to 5 hours at a time.
- Wrote a script which would identify ORCA crashes and take all necessary steps to restart without any user input. (Thanks to Mark Howe for help with the scripting language)
- Jonathan Leon and I eventually resolved the problem by updating the OS, making a fresh install of ORCA, and redoing the network connection between the DAQ computer and C1.

Efficiency of Detector

A series of radioactive sources with known activity were used to determine an efficiency for the detector as a function of energy.



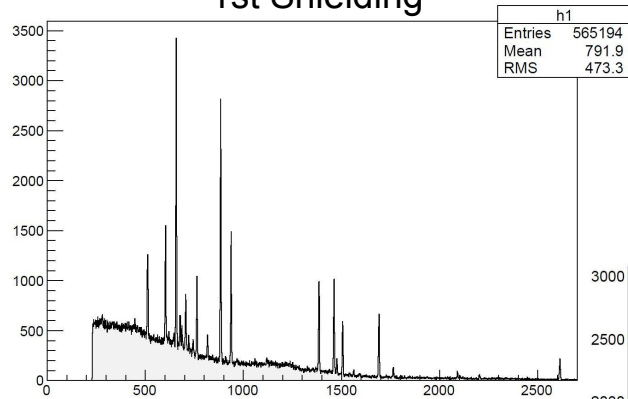
Shielding

- Originally a single layer of lead was used, which caused a 90% decrease in the overall background count rate.
 - A N_2 flushing system was simultaneously built to remove radon in the air from adding to the background. This system had minimal effect and was discarded.
- Much later, a second layer of lead was added around the first to cover any gaps through which particles could fit. This further reduced the overall background rate by 25%, and the rate in ROIs for ^{208}Tl , ^{214}Bi , and ^{40}K 50%.



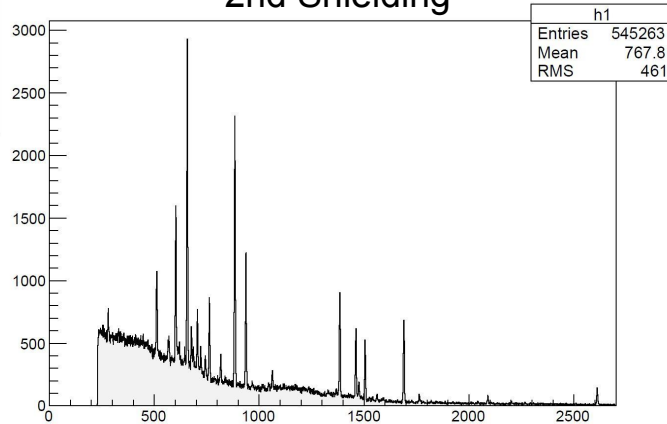
Shielding Figures

1st Shielding

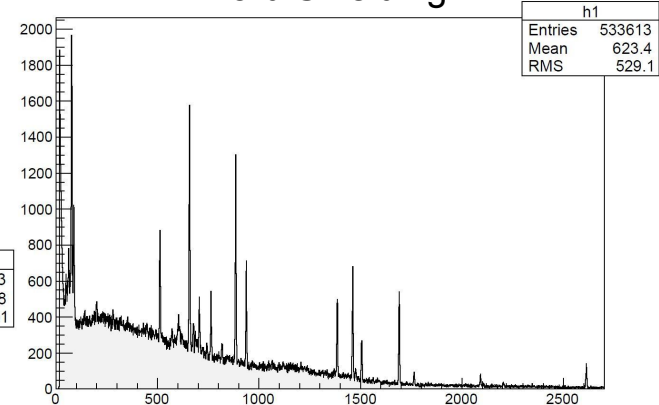


Note that this run is only for 19 hours, rather than 24 like the others

2nd Shielding



3rd Shielding



Shielding (Continued)

- The multilayered lead shield was found to have its most prominent background peaks in ^{110}Ag and ^{124}Sb . Lead is often alloyed with silver and tin. These stable elements could be converted to the unstable ones in the background through neutron capture.
- Due to other experiments in CENPA, it's quite possible that these lead bricks were bombarded by neutrons, making them active.
- The shielding was rebuilt with copper and 7 clean lead bricks. However, the copper was found to be quite active, so it was removed. The new shielding decreased the background by 50% for ^{110}Ag and 88% for ^{124}Sb .



Analysing Sample Counts

- To convert from a pure number of decays detected to an activity, we must take into account the time over which we measured decays, the mass of the sample, the efficiency of the detector, and the branching ratio
- In order to analyze data to give a confidence interval on the actual activity, Feldman Cousins statistics were used.
 - Allows use of poisson statistics in presence of background, or gaussian statistics with a physical limit.

Self-shielding Sources

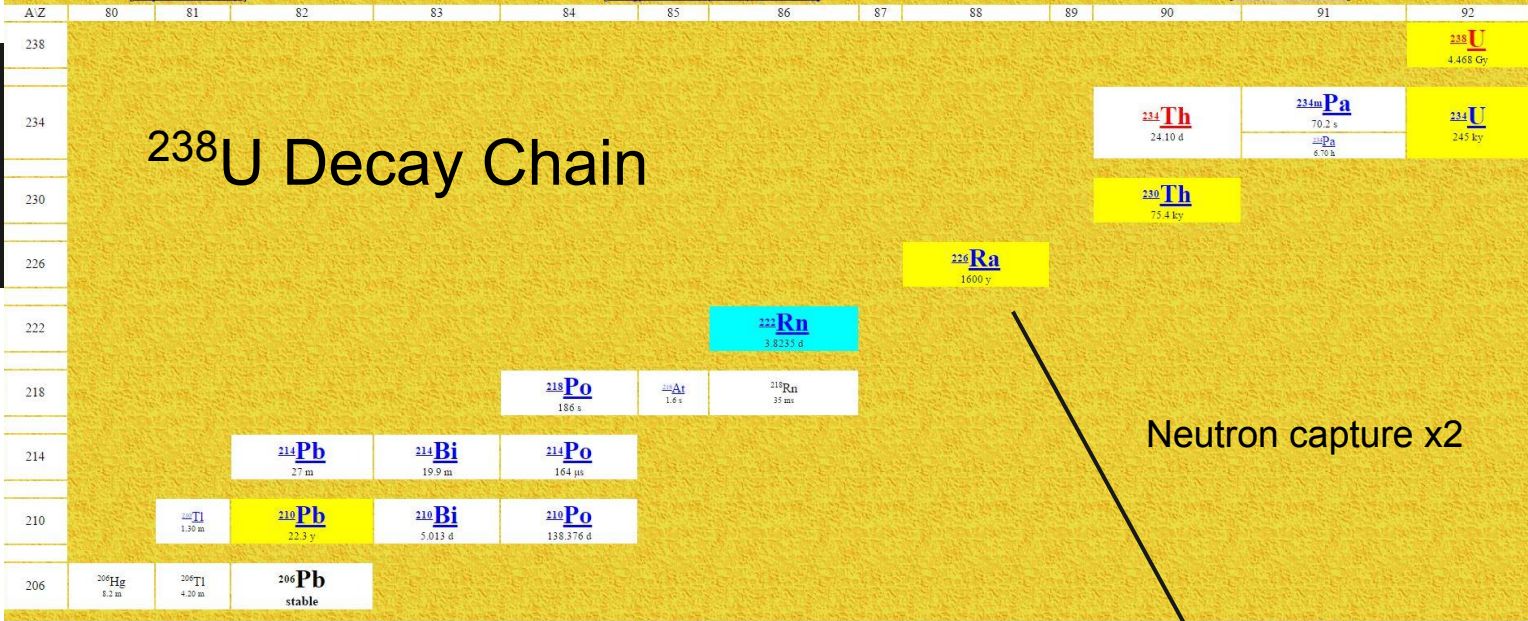
- For large samples, self shielding must be accounted for, as well as shielding of the background.
- Assume exponential form for attenuation, characterized by linear attenuation coefficient
- Integrate exponential to determine expected rate with shielding, and compare to expected rate without
- Apply this same exponential to attenuation of background counts which come through face of detector

Tungsten

- Originally believed to be depleted uranium. Lack of activity in ^{238}U decay chain proved this false.
- Tungsten source showed a higher ^{228}Ac activity than it did ^{208}Tl , despite both being generated by in the decay chain of ^{232}Th
 - Possibly due to consecutive neutron capture by ^{226}Ra to create excess ^{228}Ac , but more likely due to efficiency uncertainty
- ^{212}Pb activity also appears too high after adjusting for self-shielding, as shielding is highly dependent on photon energy.
 - No good theory to explain this

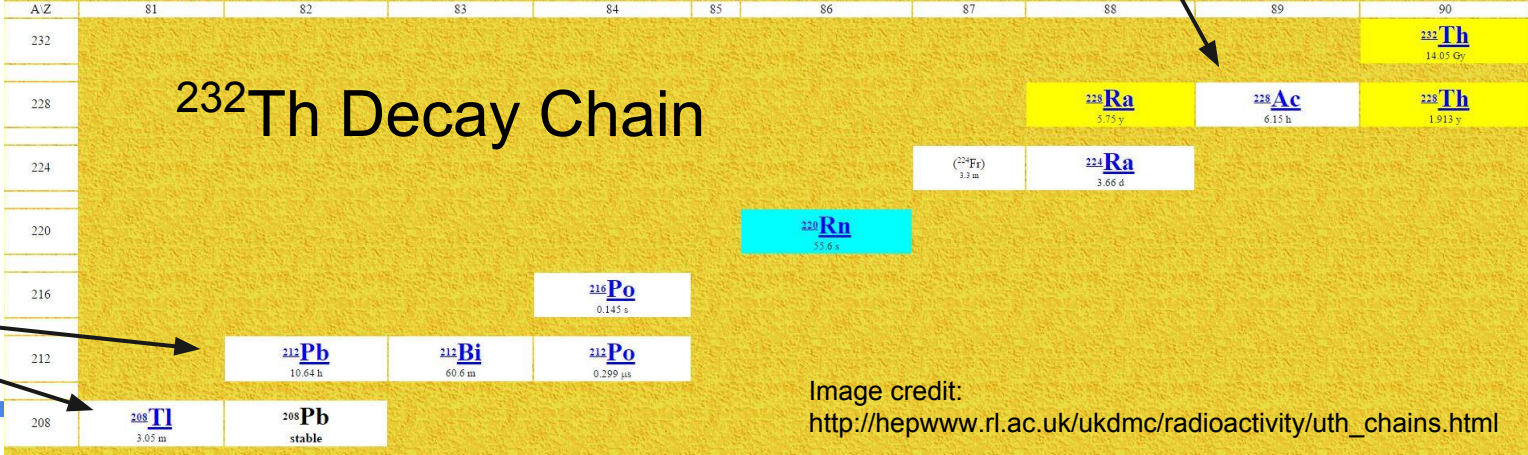
Peak	Activity (Bq/kg)
^{208}Tl (2614.5 keV)	[2.617, 2.939]
^{212}Pb (238.6 keV)	[9.923, 13.167]
^{228}Ac (911.2 keV)	[3.866, 4.401]
^{228}Ac (964.7 & 968.9 keV)	[4.611, 5.311]

^{238}U Decay Chain



Neutron capture x2

^{232}Th Decay Chain



Should be in equilibrium



Results

Sample	^{232}Th Activity (Bq/kg)	^{238}U Activity (Bq/kg) (lower chain)	^{40}K Activity (Bq/kg)
Ceramic disk capacitors	[33.603, 43.654]	[48.588, 65.105]	[.297, 43.636]
KATRIN circuit board	[0, 14.950]	[6.769, 42.484]	[0, 103.161]
BeCu block *	[0, 7.919]	[0, 14.412]	[0, 141.567]
Connectors containing BeCu	[0, 90.218]	[0, 107.727]	[0, 258.673]
Tungsten block *	[2.617, 2.939]	[0.332, 0.735]	[2.263, 3.718]
OFHC copper support	[0, 3.022]	[0, 3.032]	[0, 3.252]
Gasket Flanges	[0, 7.570]	[0, 21.139]	[0, 65.344]

* indicates self shielding calculation

Potassium in a Banana!

- ^{40}K Activity: [108.898 Bq/kg, 125.853 Bq/kg]
 - Translates to [667 mg, 771 mg] of potassium
 - This matches with the reported potassium mass concentration of bananas on the internet.
 - Definitely is a banana.
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Acknowledgements

Thanks to Jason Detwiler, Jonathan Leon, Julieta Gruszko, Clara Cuesta, Ian Guinn, Micah Buuck, Laura Bodine, and Alejandro Garcia for their help and their generosity with their time.

Thanks to the University of Washington REU and the NSF for allowing me to do this research.
