CHAPTER 1: Neutron Activation for the Majorana Collaboration

Section 1.1: Introduction

Neutron activated samples of polytetrafluoroethylene (PTFE) and fluorinated ethylene propylene (FEP) tubing were γ-assayed in the low background counting (LBC) lab at the Kimballton Underground Research Facility (KURF). Presented in this report are activities from detected isotopes, many of which are neutron activation products of transition metals.

Section 1.2: Sample Preparation

Thinly sliced PTFE samples and small sections of FEP tubing were activated on October 1, 2015, at the PULSTAR high flux reactor at North Carolina State University. Samples of varying masses as shown in Figure 1.1 were placed in glass vials and packaged for shipping to Virginia Tech. The ten vials containing 0.002-in thick PTFE samples were placed in a heat sealed plastic bag. This plastic bag was placed inside of a resealable plastic bag and labeled accordingly. The eight vials containing 0.005-in thick PTFE samples were placed in a heat sealed plastic bag along with the one vial containing FEP tubing. The samples arrived at VT on October 7, 2015. The VT Environmental Health and Safety office received the samples and checked them for external contamination leakage. None was found and all samples demonstrated no more than 0.2 mrem/hr of activity externally. Samples were transported underground via the VT state-provided diesel truck to KURF.

The samples were shipped along with vials containing neutron activated standards of ^{238}U and ^{232}Th which were used to calibrate the spectra from the samples. ~~The standards were packed inside of a sealed paint can inside the cardboard shipping container with the samples.~~ The standards were packaged in sealed plastic bags as well as shown in Figure 1.2.

Sample Parameters		Irradiated	Flux	Flux	Corrected
Index	Desc.	Mass (g)	Index	Factor	Std Mass (ug)
1	Gasket 1 - Center	8.897	2Y	1.000	8897
2	Gasket 1 - Outside	11.476	2Y	1.000	11476
3	Gasket 2 - Outside	9.867	2Y	1.000	9867
4	Gasket 2 - Inside (with small piece outer)	13.053	2Y	1.000	13053
5	Gasket 3 - Outside	13.346	2X	0.930	12412
6	Gasket 3 - Inside	12.772	2X	0.930	11878
7	Gasket 4 - Outside	11.541	2X	0.930	10733
8	Gasket 4 - Inside	8.167	2X	0.930	7595
9	Gasket 5 - Outside	12.283	3Y	0.944	11595
10	Gasket 5 - Inside	8.664	3Y	0.944	8179
11	Gasket 6 - Outside	13.574	3Y	0.944	12814
12	Gasket 6 - Outside	12.724	3Y	0.944	12011
13	Gasket 6 - Inside	10.595	3X	0.879	9313
14	Gasket 6 - Inside	10.787	3X	0.879	9482
15	Gasket 7 - Outside	12.954	3X	0.879	11387
16	Gasket 7 - Outside	13.036	1Y	0.832	10846
17	Gasket 7 - Inside	9.828	1Y	0.832	8177
18	Gasket 7 - Inside	11.635	1Y	0.832	9680
20	FEP Shrink Tube	1.034	3X	0.879	909
Standard Parameters		Transfer	Flux	Flux	Corrected
Index	Desc.	Loss	Index	Factor	Std Mass (ug)
U-1	Uranium Standard (0.5 ug initial)	0.993	4X	0.678	0.496
U-2	Uranium Standard (0.5 ug initial)	0.956	4X	0.678	0.478
U-3	Uranium Standard (0.5 ug initial)	0.977	4X	0.678	0.489
U-4	Uranium Standard (0.5 ug initial)	0.985	4X	0.678	0.493
TH-2	Thorium Standard (0.5 ug initial)	0.765	4Y	0.710	0.383
TH-3	Thorium Standard (0.5 ug initial)	0.826	4Y	0.710	0.413
TH-4	Thorium Standard (0.5 ug initial)	0.745	4Y	0.710	0.372
TH-5	Thorium Standard (0.5 ug initial)	0.693	1X	0.780	0.346

Figure 1.1: Table of masses for neutron activated samples and standards.

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Figure 1.2: Neutron activation sample packaging

Upon arrival at the lab, a sample preparation station was arranged. A table was placed outside of the detector lab with a plastic sheet on top. Everything inside of the shipping container was treated as contaminated for safety purposes. At all times, nitrile gloves were worn when handling anything that was inside the original shipping container or came in contact with something inside the shipping container. Two Marinelli beakers were designated for use in the detectors.

Section 1.3: Measurement

Measurements were made using the two detectors at the UNC low-background counting facility at KURF. The first detector,"MELISSA," is a 1.1kg, 50% RE (relative efficiency compared to NaI) Canberra LB (low-background) detector. MELISSA is oriented vertically and is cooled using a dipstick cryostat. MELISSA's shield consists of 15 cm of Doe-run lead and 2.54 cm OFHC (oxygen-free high conductivity) copper. The sample cavity is 38 cm × 38 cm × 38 cm. The FWHM at 1.33 MeV is 1.70 keV, and the threshold is 20 keV. The other detector, "VT-1," is a 0.956 kg, 35% RE ORTEC LLB Series detector in a J-type configuration. VT-1's shield consists of a 10.1-cm ORTEC commercial lead shield and 0.3 cm of OFHC copper. The sample cavity is cylindrical with dimensions 41 cm (height) × 28 cam (diameter). VT-1 has a FWHM of 1.80 keV at 1.33 MeV and the threshold is 20 keV. For more technical details regarding the facility and detector setup, see [**?**].

Each standard vial was placed in one of the detectors for 20 minutes at a time. For the first 20 minutes, the ^{238}U standard was placed in MELISSA and the ^{232}Th standard was placed in VT-1. For the second 20 minutes, the samples were each moved to the other detector. The spectrum for the ^{238}U standard in MELISSA is shown in Figure 1.3. After the standards were measured, the 0.002-in PTFE samples were placed in MELISSA and the FEP tubing samples were placed in VT-1 for assay. Emphasis was placed on these two samples at the request of the MAJORANA project engineer.

Once the standards were measured and the spectra were reviewed, the samples were

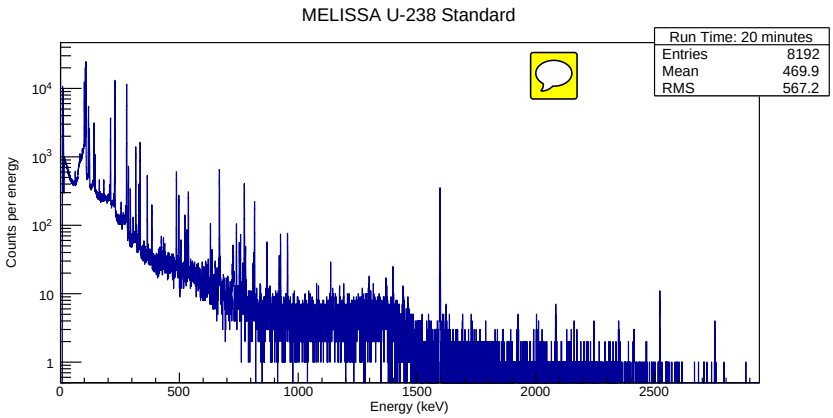

Figure 1.3: ^{238}U standard spectrum in MELISSA

placed in the detectors. The ten vials containing 0.002-in thick slices of PTFE were placed in a Marinelli beaker inside MELISSA. The samples were oriented as shown in Figure 1.4. The vial containing the FEP tubing was placed in a Marinelli beaker inside of VT-1. Both detectors were sealed and the data collection was allowed to run for 30 hours. All analysis was based on this 30-hour period.

Section 1.4: Analysis

~~For analysis, a sample spectrum is compared to the spectra for both standards. Using a library of common gamma lines seen in neutron activation, we then search for peaks that can be used to measure the activity of the sample. For the best results, well-separated peaks with the highest intensities are used. For low statistics situations such as this case, the ROI is determined using the detector energy resolution, σ_{res}.~~

The peak area of peaks in the standards are found by subtracting the continuum from the peak. The net peak area is found by subtracting the peak area of a background peak from the corresponding standard peak. The background contiuum in this case was found by fitting a linear function to a region extending $\pm 3\sigma_{res}$ from the centroid of the peak in the standard.

The activities of a specific peaks in the standards are then given by:

$$A_{\gamma s} = \frac{N}{\epsilon_\gamma m t} \tag{1.1}$$

where N is the net peak area at the energy observed, ϵ_γ is the estimated peak efficiency, t is the assay live time, and m is the mass of the standard. This activity was then used to find the initial activity for the isotopes of interest with:

$$A_{os} = A_{\gamma s} e^{\lambda \bar{t}} \tag{1.2}$$

where A_{os} is the initial activation activity, $A_{\gamma s}$ is the net peak area of the irradiated standards at known energies, $\bar{t}$ is the average time since activation, and λ is the decay constant, ~~i.e. $\frac{ln(2)}{t_{1/2}}$~~.

The same energies were then observed from samples' spectra. The ROI was defined as the same $\pm 3\sigma_{res}$ regions used to analyze the standards. If no statistically significant peak is present, an upper limit can be placed on the activity in a sample. The signal in an energy bin is then required to be less than or equal to the upper limit, 90% C.L. - 1.65σ (σ here is just the square root of the recorded counts). ~~In this case, the confidence limit was applied to a mass fraction of the identifying isotopes of the activity in the standards.~~ This ~~was~~ given by:

$$MassFraction = 1.65 \frac{\sqrt{A_p}}{t m \epsilon_\gamma} \frac{1}{A_{os}} e^{\lambda \bar{t}} \tag{1.3}$$

where A_p is the activity in the ROI for the sample, t is the assay live time of the sample, m is the mass of the sample, ϵ_γ is the estimated efficiency, A_{os} is the initial activity of the standard, $\bar{t}$ is the average time since activation, and λ is the decay constant. This mass

fraction is the activity of the calculated original activity of the sample in Bq/kg.

Section 1.5: Results

A list of γ-active isotopes found in the spectra is given for both the 0.002-in thick PTFE and the FEP tubing. All isotopes found were products of neutron activation. The isotopes of interest for this assay were products of the neutron activation of ^{238}U and ^{232}Th impurities in the samples, specifically the peaks at 106 keV for ^{239}Np and 311 keV for ^{233}Pa respectively. No statistically significant peaks were found at either energy. The calculated initial activities of ^{238}U and ^{232}Th in the 0.002-in PTFE samples was 5.15×10^{-12} Bq/kg and 3.53×10^{-12} Bq/kg respectively. The calculated initial activities of ^{238}U and ^{232}Th in the FEP tubing sample was 9.39×10^{-11} Bq/kg and 6.32×10^{-11} Bq/kg respectively.

Section 1.6: Additional Detected Isotopes

^{51}C ($t_{1/2}$ = 28d): Line at 320 keV.

^{82}Br ($t_{1/2}$ = 35h): Lines at 554, 620, 698, 764, 776, 827, 1043, 1316, and 1474 keV.

^{110}Ag ($t_{1/2}$ = 250d): Lines at 657, 707, 884, 937, and 1383 keV.

^{60}Co ($t_{1/2}$ = 1925d): Lines at 1173 and 1333 keV.

^{54}Mn ($t_{1/2}$ = 312d): Line at 835 keV.

^{58}Co ($t_{1/2}$ = 71d): Line at 810 k

^{59}Fe ($t_{1/2}$ = 44d): Lines at 1098 and 1291 keV.

^{65}Zn ($t_{1/2}$ = 1115): Line at 244d keV.

^{22}Na ($t_{1/2}$ = 3y): Line at 1273 keV.

^{24}Na ($t_{1/2}$ = 15h): Lines at 1368 and 2751 keV.

^{124}Sb ($t_{1/2}$ = 60d): Lines at 603 and 1690 keV.

^{40}K ($t_{1/2} = 1.25\times10^{9}$y): Line at 1460 keV.

^{123}Sn ($t_{1/2}$ = 129d): Line at 159 keV.