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Activation Foil Report for the June 2016 IER-151 NCERC Irradiation

Los Alamos National Laboratory
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Introduction

A critical experiment was conducted at NCERC on 6 Jun 2016. In this experiment, two sets of activation foils (Cu, Ni, Sc and Ti) were placed within the core. After the irradiation, the foils were withdrawn, packaged and set to the LANL C-NR Countroom and the foils were counted over a period of a few weeks. The results were tabulated and a simple MCNP model was created to simulate a neutron spectrum consistent with the foil results.

Irradiation

Overview

The foils were irradiated at high power for 18,060 seconds. The total integrated power was $9.72\text{e-}3$ Amp*seconds. The assembly was scrammed on June 6th, 2016 at 1745 PDT (June 7th, 0145 GMT), which corresponds to an end of bombardment (EOB) and a Counting Room zero-time of 159.0313 (2016). The samples were pulled on June 7th at 0930 PDT and foils were shipped to LANL.

This report will focus on results from the metal foils.

Counting Overview

The foils were shipped to LANL and counted from about ~1.9 days post irradiation to ~30 days. They were all counted on Counter 55. A total of 57 gamma-ray spectra were acquired from the activation foils. All of the spectra are currently stored on the Countroom Web Archive.

Activation Foils

Two activation foil stacks were used to help monitor the neutron fluence in the assembly during irradiation. Four foil materials (Cu, Ni, Sc and Ti) were selected to produce neutron interactions across the neutron energy spectrum.

The count data was initially analyzed and stored on the C-NR Countroom Archive but the initial results had been processed with library 5 which did not properly identify the peaks. The data were reanalyzed with GAMANAL [1] (June 2010 version) using library 1. The results of the analysis are show on the following pages.

In addition, a simple MCNP [2] model of the foil stack was constructed in order to make preliminary assessment of the neutron fluence and spectrum.

The results presented here are not corrected for gamma-ray self-absorption during counting. In most cases the foils are so thin and the gamma-ray energies high enough that these corrections are negligible. The MCNP model for isotope production was crude but did take neutron self-absorption into account when estimating the activation. The measured number of atoms in each foil divided by the mass of the respective foils are presented in tables 1 and 2.

Table 1. Results from 4227 Foil Stack.

		Atoms/g	Unc [%]
Cu	Co-60	6.44E+08	9.3
	Cu-64	1.27E+11	44.5
Ni	Co-58	1.75E+11	10.1
	Co-60	5.82E+09	43.5
Sc	Sc-46	3.36E+11	10.7
Ti	Sc-46	2.48E+09	14.3
	Sc-47	3.80E+09	2.0
	Sc-48	5.24E+08	21.9

Table 2. Results from 4228 Foil Stack.

		Atoms/g	Unc[%]
Cu	Co-60	1.04E+09	17.7
	Cu-64	2.17E+11	18.2
Ni	Co-58	2.46E+11	10.8
	Co-60	1.15E+09	50.4
Sc	Sc-46	3.50E+11	8.8
Ti	Sc-46	3.50E+09	13.9
	Sc-47	5.47E+09	1.9
	Sc-48	7.29E+08	25.3

Detailed Foil Analysis- 4227 foils.

The Cu foil showed evidence of Cu-64 which is from (n,g) on Cu-63 and (n,2n) on Cu-65. This short half-life isotope (12.7h) was visible over several days but at very inconsistent yields. Likewise, Co-60 was visible from several counts but quantification varied considerably. For this analysis, only the last count at Z+28.9d was to quantify the Co-60.

Figure 2. Estimated yield of Cu-64 from Cu foil in atoms at zero time for multiple counts.

The Ni foil showed evidence of Co-58 at consistent yields over all counts. Co-60 was also present but with large uncertainties (30-40% peak error).

Figure 3. Estimated yield of Co-58 from Ni foil in atoms at zero time for multiple counts.

The Sc foil showed evidence of Sc-46 from (n,g) on Sc-45. The results were consistent over all counts.

Figure 4. Estimated yield of Sc-46 from Sc foil in atoms at zero time for multiple counts.

Ti has multiple isotopes, many reactions are possible for the creation of Sc-46, Sc-47 and Sc-48. These isotopes consistent over in yield at different count times. The one exception is the Sc-46

peak was not identified on the Day 163 count, mostly because GAMANAL mistakenly identified Th-234 for the 889 keV Sc-46 peak. Also, GAMANAL consistently misidentified the Sc-47 159.5 keV peak as Te123m. So that data was reanalyzed using the GAMANAL identified yield and correcting for the proper half-life to Sc-47 to arrive at the correct yield. Note that the Sc-47 results were consistent with the expected yields from the MCNP modeling.

Figure 5. Estimated yield of Sc-46(a), Sc-47(b) and Sc-48(c) from Ti foil in atoms at zero time for multiple counts.

Detailed Foil Analysis- 4228 foils.

The results from the 4228 Cu foil still show considerable variability in the Cu-64 yield although the results are better than the 4227 Cu foil. Co-60 was observed, although at 20-30 % peak error even at later count times. For this analysis, only the last count at Z+28.0d was used for the Co-60.

Figure 6. Estimated yield of Cu-64 from Cu foil in atoms at zero time for multiple counts.

The Ni foil showed evidence of Co-58 at consistent yields over all counts. Co-60 was also present but with large uncertainties (30-40% peak error).

Figure 7. Estimated yield of Co-58 from Ni foil in atoms at zero time for multiple counts.

The Sc-46 is from (n,g) on Sc-45 and has consistent results at all count times.

Figure 8. Estimated yield of Sc-46 from Sc foil in atoms at zero time for multiple counts.

Ti has multiple isotopes, many reactions are possible for the creation of Sc-46, Sc-47 and Sc-48. These isotopes fairly consistent over in yield at different count times. Also, GAMANAL consistently misidentified the Sc-47 159.5 keV peak as Te123m. So that data was reanalyzed using the GAMANAL identified yield and correcting for the proper half-life to Sc-47 to arrive at

the correct yield. Note that the Sc-47 results were consistent with the expected yields from the MCNP modeling.

Figure 9. Estimated yield of Sc-46(a), Sc-47(b) and Sc-48(c) from Ti foil in atoms at zero time for multiple counts.

MCNP Model of 4227 Foil location.

A simple MCNP model was constructed to simulate the foil irradiation at the 4227 (LA-6) location. The geometry was a 1cm radius sphere with foils placed in the center. A neutron source sampled from a Watt fission spectrum (using the default MCNP constants) was directed into the sphere and the interior was filled with dilute (0.21 g/cm^3) H-1 to moderate the spectrum. A residual tally was used to track the production of activation products in the foils. Adjusting the intensity of the source and the H-1 density, it was possible to approximate the relative yield of most activation products, see Table 3 and Figure 10. The overall fluence was estimated to

be $\sim 3.0 \times 10^{14}$ neutrons/cm² and the lethargy plot is shown in Figure 11. The Cu foil products Cu-64 and Co-60 were both poorly fit. A better analysis of the yields of the Cu foil and a more refined MCNP modeling analysis would certainly improve these numbers.

Table 3. Isotopes and comparison to MCNP yields.

Foil	Isotope	Atoms ZT	Error	MCNP est.	C/E (4227)
		4227			
Cu	Co-60	1.67E+08	1.55E+07	2.13E+08	1.28E+00
	Cu-64	3.30E+10	1.47E+10	1.76E+10	5.33E-01
Ni	Co-58	1.51E+10	1.52E+09	1.57E+10	1.04E+00
	Co-60	9.26E+07	4.03E+07	1.10E+08	1.19E+00
Sc	Sc-46	5.34E+09	5.74E+08	5.07E+09	9.50E-01
Ti	Sc-46	1.09E+08	1.55E+07	1.19E+08	1.09E+00
	Sc-47	1.67E+08	3.31E+06	1.92E+08	1.15E+00
	Sc-48	2.30E+07	5.05E+06	2.53E+07	1.10E+00

Figure 10. Comparison of atoms at zero time for various reaction products overlaid with the MCNP C/E for each.

Figure 11. Lethargy plot of neutron fluence at the 4227 (LA-6) foil location.

Conclusions

The analytical results from this critical assembly experiment provide important information about the neutron spectrum produced in this critical assembly. The results showed a fast spectrum with a significant thermal tail.

All of the gamma-ray spectra acquired and supplemental information are captured electronically on the Countroom Web site at LANL.

References

- [1] GAMANAL, Gunnink R, Niday JD (1972) UCRL-51061
- [2] J.T. Goorley, "MCNP6.1.1-Beta Release Notes", LA-UR-14-24680 (2014).