Calibration of AFIT Graphite Pile to Account for ^{241}Am Ingrowth in the $^{239}PuBe_{13}$ Source

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INTRODUCTION

Many 1960 era Mound $^{239}PuBe_{13}$ sources exist around the country that are currently of unknown source strength. As has been well documented by E. Anderson [1,2], these sources have been increasing in strength due to the ^{241}Pu decay to ^{241}Am. The AFIT graphite pile was calibrated to account for this ^{241}Am ingrowth and the spectrum shift to provide an accurate axial flux profile that could be used in conjunction with ongoing neutron detection research.

DESCRIPTION OF THE ACTUAL WORK

This effort focused on producing computational and experimental results to accurately quantify the axial flux profile of the AFIT graphite pile. Using the 1960 National Bureau of Standards (NBS) data available for this pile, the cadmium difference thermal neutron flux was found using Au and In foil activation in combination with gamma spectroscopy. These results were coupled with computational models of the 1960 and 2010 source and pile conditions. An accurate measure of the thermal neutron flux profile was achieved through agreement of the experimental and modeling results. The measured thermal flux for the standard position was 1728 $\pm$ 86 n/cm^2-s, and the thermal flux modeled with the Monte-Carlo Neutral Particle (MCNP) code was 1679 $\pm$ 13 n/cm^2–s [3]. This agreement was achieved despite the uncertainties associated with the source composition and replication of the Au foil counting system used for comparison to the NBS data.

RESULTS

Foil Activation

Foil activation procedures, concepts, and considerations are well documented in sources such as Knoll [4] and Tittle [5,6]. It can be shown that the saturated activity is given by:

$$A_{cs} = \frac{\lambda\ C\ e^{\lambda t_w}}{(1-e^{-\lambda t_e})(1-e^{-\lambda t_c})} - \frac{A_0 e^{-\lambda t_e}}{(1-e^{-\lambda t_e})} \quad (1)$$

The cadmium difference flux can then be found from:

$$A_{th} = A_{cs} - FA_{cd} \quad (2)$$

Since the cross section varies reciprocally with the velocity, similar magnitude fluxes can be compared by [7]:

$$\frac{(A_{th})_1}{N_1(nv_0)_1} = \frac{(A_{th})_2}{N_2(nv_0)_2} = \frac{\epsilon\sigma_0\alpha}{F_{th}} = constant \quad (3)$$

Equation (3) allows for the flux at each position to be measured once the flux is known at one position. Using the 1960 calibration data for the “standard position”, position #6, the axial cadmium difference thermal neutron flux profile shown in Figure 1 was obtained.

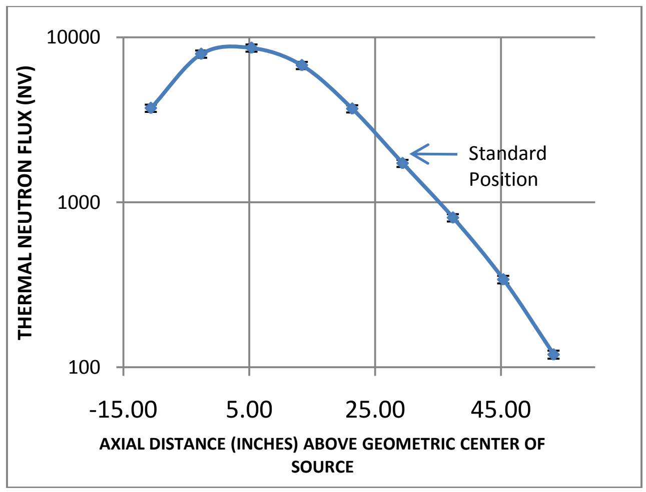

Fig 1. Cadmium Difference Thermal Neutron Flux at Various Distances from the Source

Modeling

The initial isotopics of the M-580 source were taken from nominally weapons grade plutonium [8]. These agree well with the isotopics given by Anderson for the M-591 source produced from the same batch of plutonium with the distribution used adding in the nominal ^{238}Pu and ^{242}Pu concentrations [1]. The Oak Ridge Isotope Generation (ORIGEN-S) code was then used to transmute and decay the source through the ~50 years since initial production [9]. This yielded a source strength of 1.006*10^7 n/s compared to the initial calculated source strength of 8.63*10^6 n/s. This amounts to a 16.7% increase in the yield over 50 years, consistent with the expected ~20% increase to maximum yield at ~70 years from production for the comparable M-591source [2].

SOURCES4C was used to generate a PuBe neutron spectrum from the 1960 source isotopics and one from the 2010 decayed source isotopics [10]. These spectra and isotopics were used in a MCNP5 model of the pile.

In the standard position and other close adjoining stringers, the MCNP model overestimated the 1960 measured neutron flux at each point by an average of 32.2 $\pm$ 2.8% for stringer positions #2-7. Using this correction factor for the 2010 computational data, a cadmium cut-off thermal flux of 1679 $\pm$ 13 n/cm^2–s was obtained for the standard position. This value is in good agreement with the measured flux of 1728 $\pm$ 86 n/cm^2-s.

These results provide computer models and experimental results that can be used to track the changes in flux profile of the pile over time. This experimental and computational flux profile can be used to calibrate and characterize neutron detectors that are currently being researched at AFIT. Additionally, these results and procedures could provide a methodology to define the source strength and flux profiles of many of the 1960 era PuBe sources that lack sufficient documentation to accomplish these goals by other means.

NOMENCLATURE

A_{cs} = the corrected activity for t_w, t_e, and t_c to saturation
C = counts recorded from decay of the activated nuclei
t_w = time between irradiation and the start of counting
t_e = time interval for which the foil was irradiated
t_c = time for counting the foil
A_0 = activity of the foil at the beginning of the irradiation
A_{Cd} = the activity measured activity of the cadmium foil
A_{th} = activity corrected to a Cd difference thermal activity
F = the resonance escape factor
nv_0 = the flux
ε = the efficiency of the detector
N = number of atoms in the foil
α = the self absorption factor
F_{th} = the flux depression due to an individual foil

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