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Experimental Evaluation of Neutron Spectra in a Neutron Imaging Equipment of IEA-R1 Reactor.

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1. Introduction

Understanding neutron spectra accurately is crucial for ensuring the reliable and safe operation of neutron sources and associated equipment. A comprehensive understanding of neutron spectra is essential not only for applications such as medical diagnosis, material detection, and elemental analysis but also for enhancing nuclear safety measures and optimizing reactor performance.

Achieving precise determination of neutron spectra poses significant challenges due to the intricate nature of nuclear processes involved and limitations in available experimental methodologies. Specifically, in the case of the IEA-R1 reactor imaging equipment, neutron fluxes are well-documented only in the thermal and epithermal regions of the spectrum. This leaves a notable gap in the experimental characterization of the fast neutron spectrum, which, thus far, has been exclusively understood through simulations.

In response to this knowledge gap, the primary objective of this project is to comprehensively characterize the properties of the IEA-R1 reactor imaging equipment. This will be accomplished through a combined approach involving both simulations and experimental determinations. By addressing these existing gaps in neutron spectrum understanding, this integrated methodology aims to provide a more comprehensive and accurate assessment of the equipment's operational capabilities.

To determine the neutron spectrum, various methodologies can be employed, such as Bonner spheres, proton recoil techniques, or time-of-flight spectrometers. However, these methods often present challenges due to their complex requirements. Thus, in this study, we have opted for a more feasible and accessible approach, utilizing activation foils in conjunction with simulations and computer programs.

2. Methodology

Initially, thin gold discs are employed along with the cadmium ratio technique to quantify thermal and epithermal neutron fluxes. Subsequently, the foils are irradiated to induce threshold energy reactions involving isotopes such as 115In, 56Fe, 27Al, 197Au, 48Ti, and 64Zn.

By utilizing the activities of each foil and their corresponding parameters, it becomes possible to perform the deconvolution of the activity equation and induced flux through a mathematical and iterative method, similar to approaches found in software programs and other fields of study. However, instead of traditional unfolding techniques, we utilize the least squares adjustment program STAYSL-PNNL. This program offers a solution to the spectral unfolding problem, providing an adjustment considering various important pieces of information that may be overlooked in other unfolding methods. Ideally, this includes estimates of uncertainties and covariance for activation data, dosimetry cross-sections, and neutron fluxes from the input group, all treated as independent probability density functions.

Breaking down the functions of STAYSL_PNNL, there are five distinct software tools involved. First, NJOY99 (not included) and NJpp are utilized to generate cross-section and covariance inputs from ENDF format files. Next, the neutron self-shielding corrector code SHIELD is applied. Following this, the irradiation history corrector BFC is utilized. Additionally, the Sig-Phi Calculator spreadsheets are used to calculate corrected saturated neutron activation rates. Finally, the STAYSL_PNNL software integrates all outputs and data, employing a generalized least-squares approach for Neutron Spectral Adjustment.

3. Results and Discussion

Currently, unfortunately, there have not been enough experimental data collected, and thus it has not been possible to fully complete the entire plan. Therefore, it has been decided to utilize experimental data from another irradiation location as a trial and learning experience.

Some of the data collected is presented in Table I, along with a simulated neutron spectrum generated using the Monte Carlo code MCNP, as illustrated in Figure I.

Table I: Irradiated Foils Results.

Reaction Name	Mass(g)	$A_0(Bq/g)$	Uncertainty (Bq/g)
$Fe^{56}(n,p)Mn^{56}$	0.2052	6.029	0.475
$Fe^{58}(n,g)Fe^{59}$	0.2052	$1.980 \,.\, 10^1$	0.869
$In^{115}(n,g)In^{116}$	0.0398	$4.392 \,.\, 10^1$	3.063
$In^{115}(n,n')In^{115m}$	0.0398	$5.586 \,.\, 10^2$	$4.569 \,.\, 10^1$
$Rh^{103}(n,n')Rh^{103m}$	0.0161	$3.944 \,.\, 10^4$	$1.304 \,.\, 10^4$

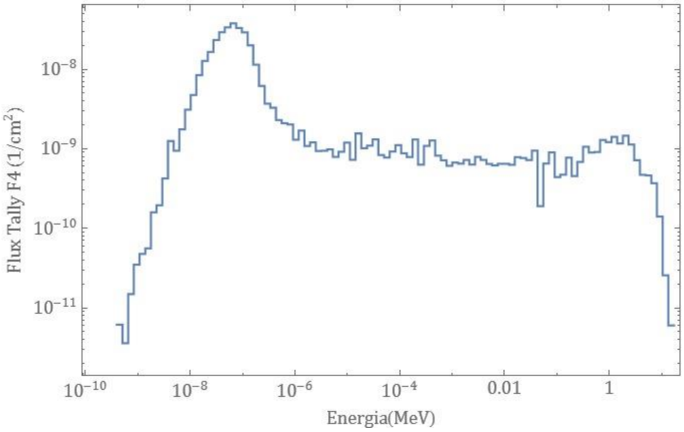

Figure I: Neutron Spectrum Simulated Using the Monte Carlo Method MCNP.

At this point, more time is needed to fully study and understand the software. Unfortunately, the utilization of the STAYSL_PNNL program has not been possible yet.

4. Conclusions

Learning how to use software like NJOY and STAYSL has been challenging due to the number of tools involved. It is hoped that proficiency with all the software, coupled with the acquisition of additional experimental foils activation input data, will be achieved by the presentation day with continued effort. However, at present, this represents the progress made thus far.

The program appears to offer a comprehensive solution to the neutron spectrum unfolding challenge and is, in some aspects, more user-friendly. It provides adjustments and incorporates estimates of uncertainties and covariances for all available input data, distinguishing it from other spectral unfolding software. With its thorough approach, STAYSL_PNNL has the potential to yield distinctly favorable results.

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