Neutron Energy Spectra Characterization Using a ^{3}H Neutron Spectrometer

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Introduction

Neutron beams are used in a variety of experimental methods at research reactors all across the United States. Such applications include: neutron imaging and neutron tomography, neutron depth profiling, neutron diffraction, neutron scattering etc. The aforementioned techniques employ neutron interactions, which are characterized by energy dependent cross sections. Accordingly, information characterizing the energy spectrum of these neutron beams is useful.

Spectrometer Characterization

A Model 525-780 ^{3}He spectrometer was purchased from ORTEC and is currently being tested and calibrated at the Radiation Science and Engineering Center (RSEC). Current thermal neutron beam energy measurements are performed using a slow neutron chopper, which employs the time-of-flight technique. However, the maximum detectable neutron energy is bound by the mechanical limitations of the slow neutron chopper, specifically the rotational speed of the chopper disk. The ^{3}He spectrometer provides the experimenter with the ability to characterize neutron energies in the hundreds of keVs to the MeV range. Figure 1 is a photograph of the ORTEC Model 525-780 ^{3}He Spectrometer. Appendix A is a schematic of the pulse processing circuit. The spectrometer included: two surface barrier detectors mounted 1 mm apart in side a sealed spectrometer head, a bottle of ^{3}He gas that allows for up to 80 refills of the spectrometer head at an internal pressure of 5 atm, the necessary nuclear instrumentation and the associated power supplies.

The spectrometer uses the $^{3}He(n,p)^{3}H$ reaction. This is an exothermic reaction in which the resulting reaction products (a proton and a triton) share the Q-value of the reaction (764 keV) as well as the kinetic energy of the incident neutron. The "head" of the ^{3}He neutron spectrometer contains two surface barrier detectors in a sandwich geometry. The energies of the reaction products are deposited in these detectors and output pulses are generated. The height of the output pulses is directly proportional to the incident neutron energy. These pulses are processed by summing and coincidence circuits. The pulse height analyzer used in this system is an ORTEC TRUMP – PCI card. The ADC on this card is gated using the output from the coincidence circuit in the instrumentation and the neutron energy information is collected from the summing circuit. The system is made portable with the addition of a PCI expansion box from MAGMA electronics. This device houses the TRUMP – PCI card in a fashion similar to a regular desktop PC but connects to a laptop computer using a PCMCIA card. The raw neutron energy spectra from various sources (e.g. plutonium-beryllium source, americium-beryllium source, neutron beam) are collected and visually displayed using ORTEC's MAESTRO – 32 MCA Emulator. A typical raw neutron energy spectrum is shown in Figure 2.

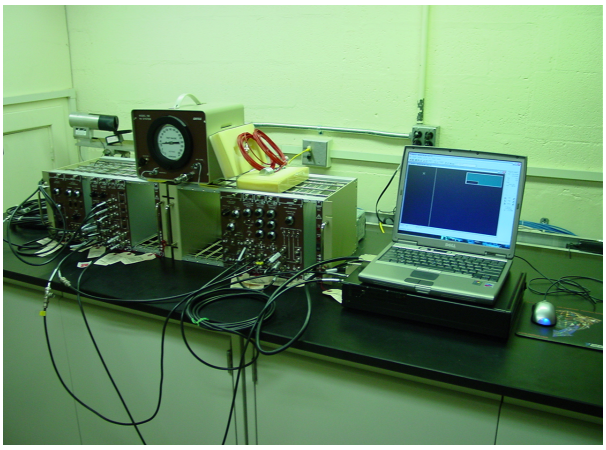

FIGURE 1: ^{3}He spectrometer with PCI expansion box and Dell Laptop used for data collection

The ^{3}He neutron spectrometer is calibrated using an ORTEC Model 419 Precision Pulse Generator (pulser). The system was calibrated at ORTEC during the initial testing phases so that the pulse height dial reading on the front of the module corresponds to signal pulses from 0 to 10 MeV. The energy calibration in MAESTRO – 32 is preformed by obtaining multiple pulser peaks in a single spectrum and assigning energy values to each peak. The energies of the channels not in the peaks are extrapolated using a quadratic fitting process. Figure 3 shows a spectrum of pulser peaks used for a calibration.

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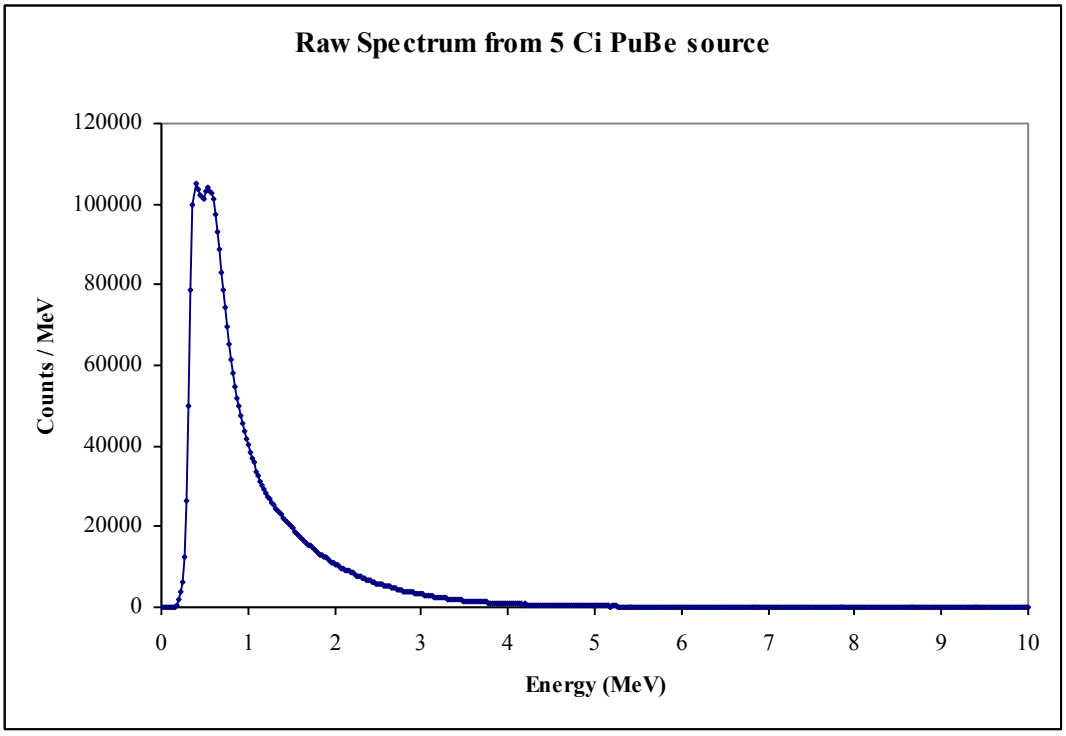

FIGURE 2: The raw neutron spectrum collected from a 5 Ci plutonium-beryllium source

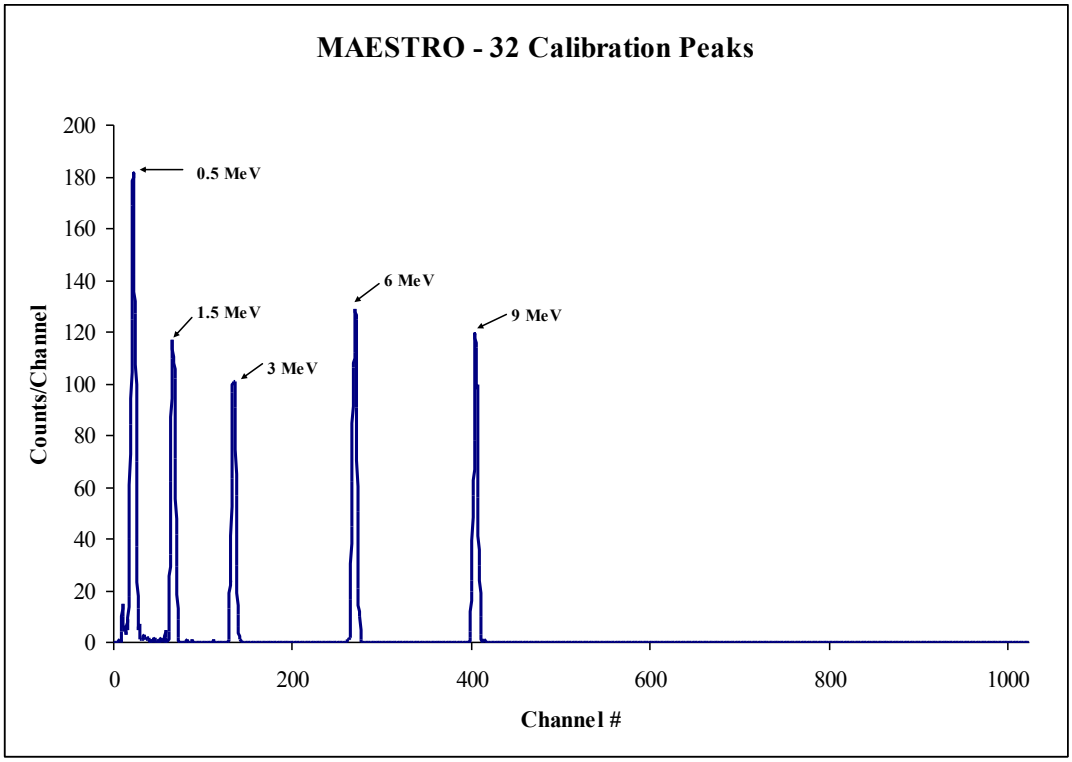

FIGURE 3: Peaks produced in the pulser for use in the energy calibration procedure

Most of the measurements made to date were collected using a 5 Ci plutonium-beryllium source located at the RSEC. The source is positioned in the same azimuthal plane (approximately 3 ft from the floor) as the detector at a distance of 25 cm. Initial measurements were made with the detector and source much closer together in order to increase counting rates; however, indications of detector saturation were noticed, which is why the source was moved to 25 cm away from the detectors. At this distance the neutron flux incident on the detector (assuming point source and point detector for simplicity) is approximately 2.5 x 10^7 $^{n}/_{cm^2 s}$.

The raw spectral data (counts/channel or MeV), as shown in Figure 2, collected with the spectrometer is actually the number of (n,p) reactions per channel/energy for the spectrum collection time. While this is an accurate number in terms of (n,p) events occurring in the detector head, this information does not accurately represent the actual neutron spectrum emitted from the plutonium-beryllium source (or from any other source).

Many phenomena must be considered when trying to extract the actual neutron spectrum from the information collected using the spectrometer. These considerations include the ^{3}He cross-section, $\sigma_{n,p}$, the spectrometer efficiency and resolution, response functions of the detector, and so on. For simplicity, it was assumed that the reaction rate per MeV (RR), mentioned earlier, was related to the flux by the equation:

$$RR(E) = N\sigma(E)\varphi(E)\ ,$$

where *N* is the number of ^{3}He atoms in the detector head and is relatively constant throughout the collection time. The ^{3}He cross-section, $\sigma_{n,p}$, was acquired from the ENDF/B database and a polynomial fit was applied to the data in order to obtain energy dependent equations that could be used to unfold the neutron spectra. These polynomial fits are shown in Figure 4.

Another major consideration that was originally overlooked was the inclusion of the Q-value of the reaction in the reported neutron energy. The raw data is shifted in energy by about 764 keV because the sum of the kinetic energies of the proton and the triton is given by:

$$KE_{p,t} = KE_p + KE_t = KE_n + Q.$$

Neutrons with initial energies in the thermal range (E = ~0) will appear in the raw spectrum to have energies of 764 keV. This additional Q-value energy can be subtracted during the energy calibration process so that the incident neutron's actual energy is recorded in the spectrum.

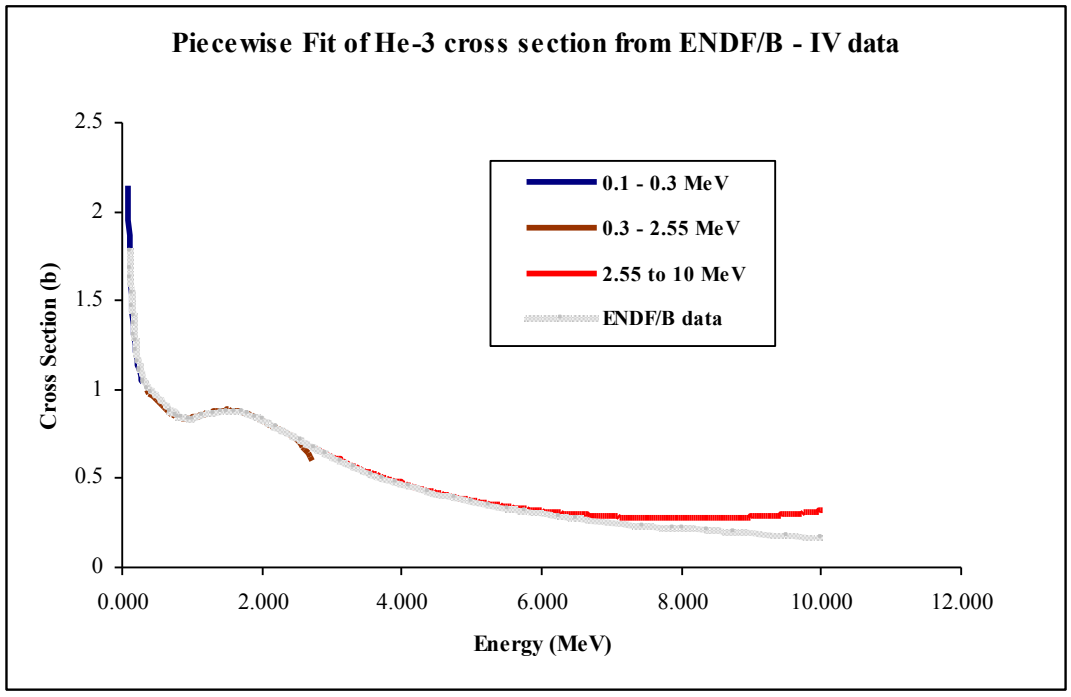

FIGURE 4: Polynomial piecewise fit to the ENDF/B cross section for the ^{3}He (n,p) reaction

A current effort is underway to determine if the response function of the system should also be considered when unfolding the raw neutron spectra. The response of the spectrometer is likely a function of the system efficiency, which varies by several orders of magnitude for thermal and fast neutrons (e.g. $\varepsilon = \sim 10^{-2}$ for thermal, $\sim 10^{-6}$ for fast).

As mentioned, there are still issues that need to be accounted for before a completely unfolded or deconvolved neutron spectrum can be obtained. The ultimate goal, once a neutron spectrum can be extracted from the raw data, is to combine the ORTEC Model 525 – 780 Neutron Spectrometer with the portable slow neutron chopper, which was developed at Ward Center for Nuclear Science at Cornell University and the RSEC at the Pennsylvania State University, into one unit that can be transported to different research neutron beams for characterization purposes.

Appendix A