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Fast Neutron Spectroscopy using a Neutron Scatter Camera

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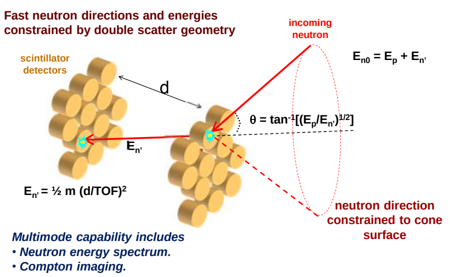
Introduction

In addition to being a useful tool in determining source angular position, the Neutron Scatter Camera (NSC) simultaneously measures source neutron energy spectra. This faculty could play an important role in distinguishing various neutron sources, e.g. fission, (α,n) and (γ,n) reactions, cosmic ray, and D-D or D-T fusion concurrently with forming an image. We undertook this work with the specific goal of determining how the spectra measured by the NSC would compare to previously determined spectra. The ^{241}Am-Be radioactive source is widely used in many applications ranging from detector calibration to oil well logging. ^{241}Am-Be is therefore the most likely neutron source encountered in cargo, and discerning it from fission spectrum neutron sources is of importance.

Measurement Approach

Neutron Scatter Camera



The NSC has been specifically designed to be sensitive to fission energy sources between 1 MeV and 10 MeV. It consists of 32 EJ-309 liquid scintillator cells arranged in two planar arrays of 16 cells each. Each cylindrical cell is optically coupled to a single photomultiplier tube (PMT).

The detector sizes and spacing were extensively investigated using MCNP-PoliMi to model and optimize our design. In order to calculate the neutron energy with double scatter events, two parameters must be experimentally determined: the energy of the recoil proton, E_p, in the first scatter and the TOF between the two scatters. The recoil proton energy, Ep (in MeV), is calculated by inverting an empirically determined light yield function (LYF) of the form:

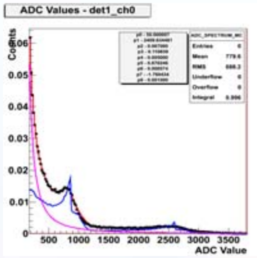
$$L = a*E_p^2 + b*E_p + c \quad (1)$$

where L is the measured light output (MeVee) and a, b and c are coefficients for the LYF. In the absence of available published data, the LYF we used for EJ-309 was obtained from preliminary results presented by Enqvist et al. The values of the parameters for equation (1) that we used in this work are:

$$a = 0.03495,\ b = 0.1424 \text{ and } c = -0.0362$$

Calibrations of the electron-equivalent energy scale are typically performed using a ^{22}Na source. PMT voltages are set to make the 1.275 peak coincide roughly ¾ of the full ADC range. This response is compared on a cell by cell basis to a resolution smeared MCNP simulation of the same source. The fit to this response allows for shifting in background and stretching/skewing due to non-linear ADC or scintillator response. An example output is shown below.

The Neutron Scatter Camera



Energy Calibration: ^{22}Na source

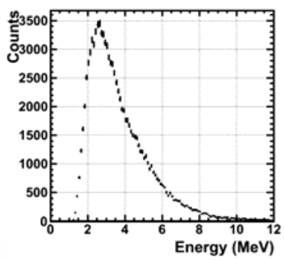
The Experiment

The experiment was conducted in a large high-bay hall far from walls or obstructions to minimize the effect of scattered neutrons. The sources were placed 2 meters from the front plane of the detector on an aluminum board, 142 cm above a concrete floor, with no other local obstructions. The source strengths were well over background and measured at the same position in quick succession over a period of 24 hours to reduce any systematic angular or temporal variations. The experiment was modeled using MCNP-PoliMi. All simulations were conducted with sources in a configuration identical to the physical experiment setup. The full detector and a finite concrete floor were included in our model. A total of 6 x 10^9 neutron events were simulated emerging isotropically from the source location with initial energies in a flat distribution from 0.1 MeV to 10 MeV. These events were analyzed and reconstructed with the same code used for experimental data.

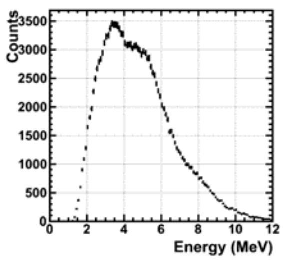
In order to convert a raw measured neutron energy spectrum into an estimate of the true source spectrum, energy resolution and misreconstruction effects must be unfolded. From the simulated events, we generate a response map; essentially a set of probability density functions (p.d.f.'s). Each p.d.f. contains the probability distribution for observed energies given a detected event emitted from the source with some true energy; the full response map is a set of p.d.f.'s spanning the true energy range of interest (1.5–9.0 MeV). A maximum likelihood expectation maximization (MLEM) procedure uses this response map to determine the Fast Neutron Spectroscopy using a Neutron Scatter Camera source energy distribution that is most likely to produce the observed spectrum. The regularization approach used is simply to stop the MLEM procedure after an arbitrary number of steps (40), when the gross spectral features have been determined, but before significant noise has been introduced.

Experimental Results

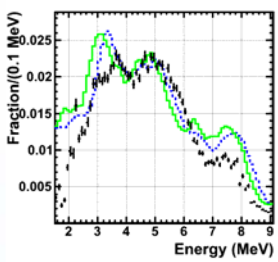
Below we show the raw observed neutron energy spectrum from ^{252}Cfas well as the ^{241}AmBe spectrum as measured by the NSC. Comparing the two, significant differences can be seen between the ^{241}AmBe spectra and the ^{252}Cf spectra even before correcting for energy efficiency. The ^{241}AmBe shows evidence of distinct features while the smooth ^{252}Cf spectrum does not.



Raw ^{252}Cf neutron energy spectrum as measured by the NSC.



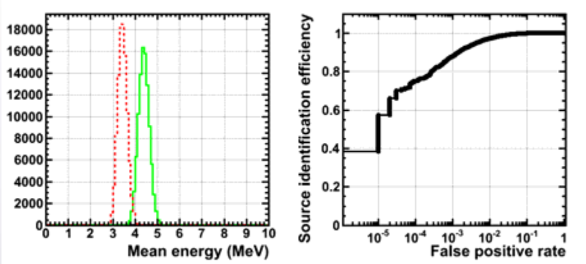
Raw ^{241}AmBe neutron energy spectrum as measured by the NSC.



Left: We compare the unfolded ^{241}Am-Be spectrum with two reference spectra: the ISO 8529-1 standard (in green), and the measurement from Geiger (in blue). Again the curves are normalized to the data in the core 4–7 MeV region of the spectrum. Our results show the best agreement with the Geiger spectrum; however, we have noted significant differences in the spectrum when an alternative LYF is used. Attempts to reduce the uncertainty on this function are underway.

Comparison of unfolded ^{241}AmBe spectra (points) with the ISO 8529-1 standard (green solid line) and the measurement from Geiger (blue dashed line).

We have directly analyzed the power of discrimination between the two sources shown here. A receiver-operator characteristic (ROC) curve is an appropriate tool to evaluate this capability. We fix the sample size to 50 events, which corresponds to tens of seconds of data for a nearby bare source of significant strength. The comparison is best done using raw measured energy (Figure 1, Figure 2), since the absolute spectrum is not of interest here. We found that for 50 events, a simple mean observed energy is a sufficient test statistic for excellent discrimination between the two bare source spectra where background is negligible. For a false positive rate of 1%, for example, ^{252}Cf could be successfully identified with 97% efficiency.



Conclusions and Future Work

Neutron energy spectrum measurements are inherently limited by the NSC's energy resolution, which is dominated by the energy resolution of the liquid organic scintillator. However, they do show reasonable agreement with the expected spectra after an unfolding analysis to correct for resolution effects. These results show that the NSC can discern between source spectra, and that our MCNP-PoliMi model agrees with data reasonably well to help predict NSC energy response.

ACKNOWLEDGEMENTS

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