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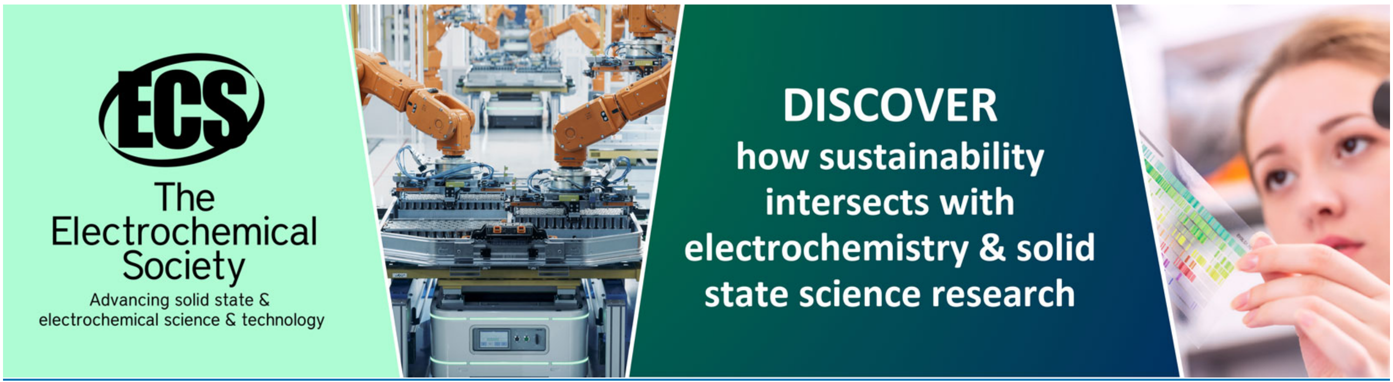

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Two detector arrays for fast neutrons at LANSCE

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ABSTRACT: The neutron spectrum from neutron-induced fission needs to be known in designing new fast reactors, predicting criticality for safety analyses, and developing techniques for global security application. The experimental data base of fission neutron spectra is very incomplete and most present evaluated libraries are based on the approach of the Los Alamos Model. To validate these models and to provide improved data for applications, a program is underway to measure the fission neutron spectrum for a wide range of incident neutron energies using the spallation source of fast neutrons at the Weapons Neutron Research (WNR) facility at the Los Alamos Neutron Science Center (LANSCE). In a double time-of-flight experiment, fission neutrons are detected by arrays of neutron detectors to increase the solid angle and also to investigate possible angular dependence of the fission neutrons. The challenge is to measure the spectrum from low energies, down to 100 keV or so, to energies over 10 MeV, where the evaporation-like spectrum decreases by 3 orders of magnitude from its peak around 1 MeV. For these measurements, we are developing two arrays of neutron detectors, one based on liquid organic scintillators and the other on ^{6}Li-glass detectors. The range of fission neutrons detected by organic liquid scintillators extends from about 600 keV to well over 10 MeV, with the lower limit being defined by the limit of pulse-shape discrimination. The ^{6}Li-glass detectors have a range from very low energies to about 1 MeV, where their efficiency then becomes small. Various considerations and tests are in progress to understand important contributing factors in designing these two arrays and they include selection and characterization of photomultiplier tubes (PM), the performance of relatively thin (1.8 cm) ^{6}Li-glass

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scintillators on 12.5 cm diameter PM tubes, use of 17.5 cm diameter liquid scintillators with 12.5 cm PM tubes, measurements of detector efficiencies with tagged neutrons from the WNR/LANSCE neutron beam, and efficiency calibration with ^{252}Cf spontaneous fission neutrons. Design considerations and test results are presented.

KEYWORDS: Scintillators, scintillation and light emission processes (solid, gas and liquid scintillators); Neutron detectors (cold, thermal, fast neutrons)

Contents

2012 JINST 7 C03028

1 Introduction

The neutron spectrum from neutron-induced fission needs to be known in designing new fast reactors, predicting criticality for safety analyses, and developing techniques for global security application. The experimental data base of prompt fission neutron spectra (PFNS) is very incomplete and most present evaluated libraries are based on the approach of the Los Alamos Model [1]. To validate these models and to provide improved data for applications, a program is underway to measure the fission neutron spectrum for a wide range of incident neutron energies using the spallation source of fast neutrons at the Weapons Neutron Research (WNR) facility at the Los Alamos Neutron Science Center (LANSCE).

The problem in the present PFNS data is exemplified in fission of the common isotope ^{239}Pu, where there are very few measurements with fission induced by fast neutrons. Two measurements [2, 3] that seem to have been done carefully are illustrated in figure 1 where the spectra are presented for clarity as ratios to a Maxwellian with T=1.30 MeV. The ENDF/B-VII.0 evaluation [4] is also given on the figure. The measurements were made with different incident neutron energies, 0.215 and 0.50 MeV, but all theoretical models predict only a very slight change in PFNS with incident neutron energy. We can therefore say that the measurements are discrepant.

Knowledge of prompt fission neutron spectra is important throughout the energy range of the emitted neutrons. For high energies, above about 6 MeV, the fission neutrons can induce reactions on structural materials in a reactor that contribute to the radiation-induced changes in the materials properties. It is well known that accumulation of helium, produced by (n,alpha) reactions, for example, can have deleterious effects. To assess the performance of materials, quantitative estimates of helium production must be made. At the lower end of the PFNS, the number of emitted neutrons must be known in order to know the relative number of MeV neutrons due to the fact that the total number of prompt fission neutrons, “nu-bar”, is known rather accurately by measurements over a wide range of incident neutron energies. More low energy neutrons (<1 MeV) means

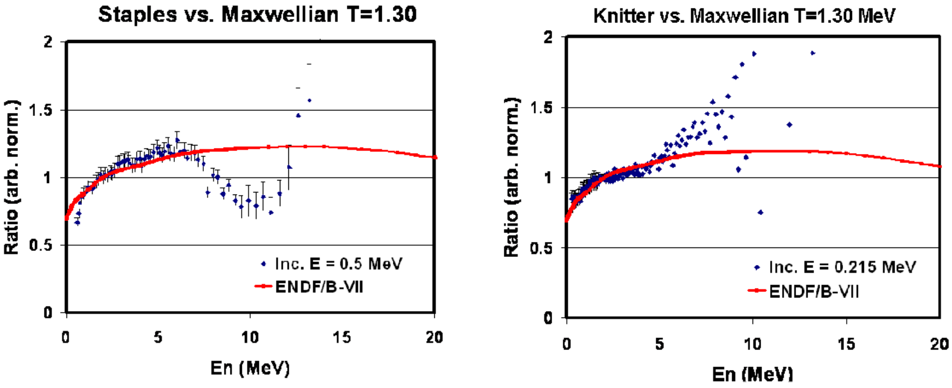

Figure 1. Data on the prompt fission neutron spectra from neutron induced fission of ^{239}Pu plotted as a ratio to a Maxwellian spectrum with T=1.30 MeV. The data were measured at two somewhat different incident neutron energies of 0.5 MeV [2] and 0.215 MeV [3], but the change in fission neutron spectra over this energy range is believed to be very small. Predictions from the ENDF/B-VII.0 evaluation are also shown [4].

fewer neutrons at higher energies. In physics models of the PFNS, there remains the question of neutrons emitted before scission, e.g. [5], and these neutrons would likely have low energies. New measurements would address this physics issue.

This report describes progress in the development of neutron detectors to measure prompt fission neutron spectra. Two different arrays are under development, one to detect neutrons above 0.6 MeV and the other to detect neutrons below 1 MeV down to perhaps 50 keV. Nearly all of the fission neutrons would then be measured. The arrays of course could also be used for other neutron emission measurements such as (n,n'gamma) [6].

2 Detector selection

2.1 Liquid organic scintillators

Liquid organic scintillators such as NE213 and its descendents (BC501A, EJ301) have long proven their usefulness in detecting fast neutrons [7]. They are fast and they can separate neutrons from gamma rays by pulse-shape discrimination for sufficiently large pulse heights, which correspond to neutron energies above about 600 keV [8]. Because of the well developed technology, we choose this sort of detector for detecting neutrons above 600 keV.

Recently another liquid scintillator with similar properties has become available with about the same light output, slightly slower response, and slightly inferior pulse-shape discrimination. It is marketed as EJ309 [9, 10] and BC599-17 [11], and it has a much higher flash point for safer handling. The performance of this new scintillator is compared with the older type in table 1. Because we need the highest efficiency for a 5 cm thick detector, we choose this new scintillator because of its higher hydrogen atom density. The other advantage is the higher H/C ratio. Because neutron scattering from one detector to another often originates with scattering from carbon, we wish to minimize the carbon content of the scintillator.

Previously [12] we used scintillators that are 12.5 cm in diameter. We wish to increase the solid angle subtended by them and so have enlarged the diameter to 17.8 cm, viewed by a 12.5 cm

Table 1. Properties of some liquid scintillators for neutron detection.

Scintillator/property	EJ301=BC501A = NE213	EJ309 = BC599-17	EJ309/EJ301
Density (g/cc)	0.874	0.959	1.097
H/C ratio	1.212	1.25	1.031
H atoms/cc — $\times 10^{22}$	4.82	5.46	1.133
H atoms/cc — $\times 10^{22}$	3.98	4.37	1.098
Decay time (short) ns	3.2	3.5	

Figure 2. Arrangement of 27 liquid scintillators, which constitute half of the array. The neutron detectors will be 1.0 m from the fission chamber. The array of ^{6}Li-glass detectors will be smaller in number and will be at a flight path of 40 cm from the fission source.

diameter photomultiplier tube. The thickness is still 5 cm, so that the transit time of a 1 MeV neutron is 3.7 ns. This time uncertainty will be folded into the analysis of the time-energy correlation. The efficiency of neutron detection varies with energy and is a maximum of about 50% at 1 MeV with a 40-keV electron-equivalent threshold.

The array is planned to consist of up to 54 detectors located at 1 meter from the fission chamber. A strong but relative low mass support structure is based on rectangular tubes, bent to the appropriate radius (figure 2).

2.2 Lithium-glass scintillators

To detect neutrons below 600 keV and to discriminate them from gamma rays, we will use ^{6}Li-glass scintillators which operate on the reaction ^{6}Li(n,alpha)^{3}H with a positive Q-value of 4.8 MeV. The scintillators are 10 cm in diameter, 18 mm thick, and mounted on a 12.5 cm diameter photomultiplier tube. These detectors have excellent efficiency at low neutron energies (below 10 keV) and at the 250 keV resonance in the ^{6}Li(n,alpha) reaction. At other energies, their efficiency is less than that of the organic scintillators, a disadvantage but one that is necessary to obtain spectra free of gamma-ray contamination. Quantification of gamma-ray backgrounds will be carried out with ^{7}Li-glass scintillators of the same dimensions. To increase the solid angle covered by the detectors, the scintillators will be located 40 cm from the fission chamber. Development work on these detectors is described by Lee et al. [13].

3 Preliminary test results

3.1 Position dependence of detector response

With scintillators of large area coupled to large diameter photomultiplier tubes (PMT), it is important to know the position-dependent response and, hopefully, to minimize variations. For a 17.8 cm diameter liquid scintillator coupled to a 12.5 cm diameter PMT, the dependence could be significant. We have made preliminary measurements of prototype detectors where the liquid scintillator is coupled directly to the PMT without a light guide that could spread the scintillation light more evenly over the surface of the PMT and its photocathode. A ^{137}Cs gamma-ray source was collimated to 3 mm in diameter and directed to various positions on the scintillator. The output signal from the detector was measured and the half-height of the Compton edge was recorded. Measurements were made both with the 17.8 cm diameter scintillator and the older 12.5 cm diameter scintillator. Each scintillator was viewed by its own 12.5 cm diameter PMT, model R1250A from Hamamatsu. The values normalized to a central position are shown in figure 3, where it is seen that the response for both scintillators falls off on the order of 11–14% from the center to the outer edge. The larger diameter scintillator is not significantly worse than the smaller one, which might suggest that the differences in response are not due to the size of the scintillator but rather to the response of the PMT as a function of position. Tests with small scintillators on the face of the PMT show that the PMT response does vary significantly over its face. We were unable to obtain specifications from the manufacturer on what sort of variation is expected and whether the variations vary among individual PMTs of the same model.

The results of these tests of detector non-uniformity have led us to two design changes. We will insert a light guide between the scintillator and the photomultiplier tube in order to spread the light more evenly on the photocathode. Further, we will taper the light guide so that only the center 10 cm diameter of the photocathode will be used. Finally, we now recognize that there will still be non-uniformities in response, and we will need to characterize them for precise modeling of the response.

3.2 Approaches to measuring detector efficiency

To obtain data of good accuracy on the shape of the PFNS, the efficiency of neutron detection needs to be known very well. We are using three different approaches to determine the efficiency: (1) PFNS from spontaneous fission of ^{252}Cf, which is contained in a fission chamber; (2) well-studied neutron fields produced at low energy accelerators; and (3) tagged neutrons at the WNR/LANSCE facility.

Spontaneous fission of ^{252}Cf produces a prompt fission spectrum that has been studied extensively [14] and is available in the most recent evaluated nuclear data files [4]. If the fission occurs in a fast fission ion chamber, then by time-of-flight, the efficiency of the neutron detectors can be

2012 JINST 7 C03028

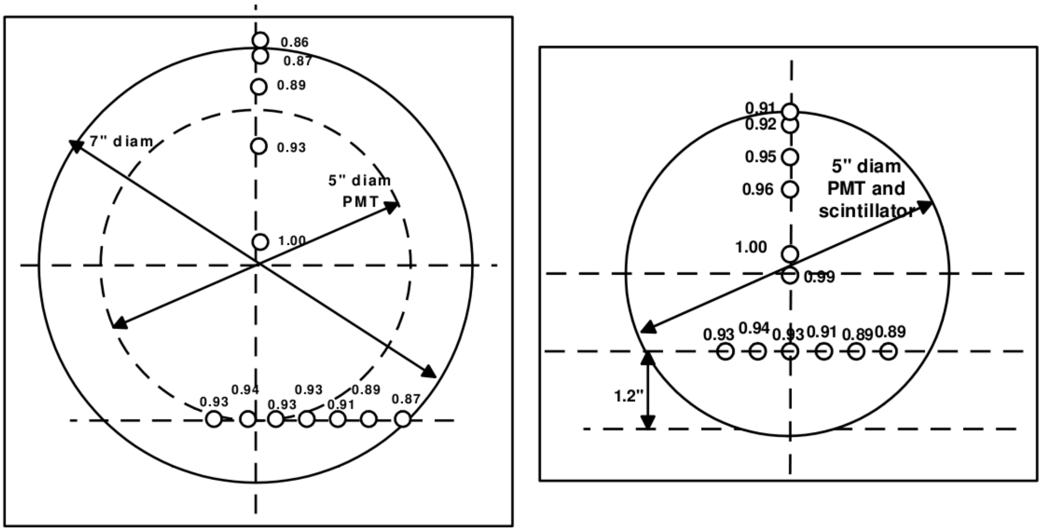

Figure 3. Relative pulse-height response to gamma rays across the face of the liquid scintillator. The dimensions are in inches; left panel: 7” (17.8 cm) scintillator — the 5” (12.5 cm) PMT area is outlined by the dashed circle; right panel: 5” (12.5 cm) scintillator.

determined as a function of neutron energy. We now have a fission chamber that is identical to that used in the ^{239}Pu(n,f) measurements, so that the effects of scattering from the chamber structure and objects in the experimental area will be the same. The only drawback from this approach is that the fission spectrum drops off by two or three orders of magnitude from its peak around 1 MeV to 10 MeV (as in the ^{239}Pu measurement), and therefore the counting time for the calibration can be lengthy at the high end of the neutron spectrum.

Well-studied neutron fields are available at several accelerator facilities such as that at Ohio University, where the ^{27}Al(d,n) reaction on a stopping aluminum target has been carefully quantified from 0.2 to 14.5 MeV [15]. The drawback of this approach is that the detectors need to be transported to the facility and the experimental environment (detector stands, room floor and walls, etc.) will be different. Also the standard spectra also drop off significantly at the higher neutron energies. Other laboratories that offer well characterized monoenergetic neutron fields are in Europe at the Physikalisch-Technische Bundesanstalt (PTB) in Germany, the National Physical Laboratory (NPL) in the United Kingdom, the Institut de Radioprotection et de Sûreté Nucléaire (IRSN) in France and the Institute for Reference Materials and Measurements (IRMM) in Belgium.

Neutron tagging has been developed at WNR/LANSCE, with a setup shown schematically in figure 4, where neutrons from the spallation neutron source scatter from hydrogen in a CH_2 foil. The recoil protons are detected at a selected angle with a ΔE-E telescope and the associated scattered neutron goes at the complementary angle on the other side of the beam. For every detected proton, there is guaranteed to be a neutron at this complementary angle. This approach has a good counting rate for detected neutron energies from 1 MeV to well above 20 MeV and therefore complements the other techniques. The drawback is that the detected neutrons need to be incident on the active face of the scintillator, and for practical purposes, this means that the neutrons do not cover the full face of the scintillator. Corrections for edge effects and scattering from the scintillator

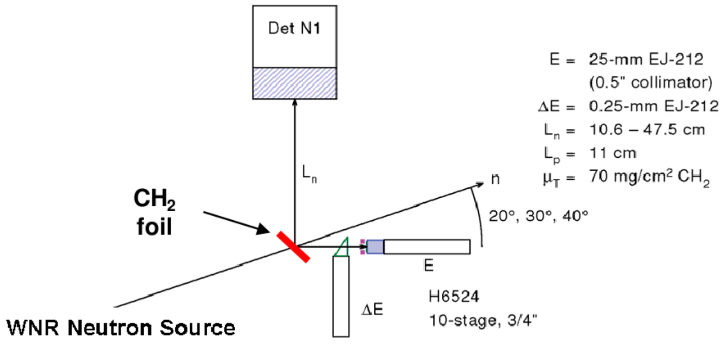

Figure 4. Schematic setup for neutron tagging at WNR/LANSCE. The efficiency of neutron detector N1 is to be determined. Neutrons from the pulsed source scatter from hydrogen in a CH_2 foil; recoil protons are detected at a chosen angle by a DE-E counter telescope of plastic scintillators; the associated scattered neutrons go at the complementary angle to the neutron detector.

housing, PMT magnetic shield, and supporting structure need to be calculated. This approach has been used elsewhere to determine detector efficiencies [16, 17] and to better than 2% accuracy in the range 2-11 MeV [16]. Further corrections will need to be made based on the measured non-uniformity of response as discussed above in section 3.1.

4 Summary

To measure the prompt fission neutron spectra from neutron-induced fission, two detector arrays are being constructed at WNR/LANSCE. Fission neutrons above 600 keV will be detected by EJ309 liquid scintillators. Neutrons below 1 MeV will be detected by an array of ^{6}Li-glass scintillators. An overlap region from 600 keV to 1 MeV will therefore be available to connect the measurements and give data from approximately 50 keV to 12 MeV.

Acknowledgments

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