

# MEASUREMENT AND SIMULATION OF LIQUID SCINTILLATOR NEUTRON RESPONSE

Lucia Cartegni\* and Sara A. Pozzi  
Oak Ridge National Laboratory  
P.O. Box 2008, MS-6010, Oak Ridge, TN 37831-6010

## ABSTRACT

This paper presents the results of measurements and Monte Carlo simulations aimed at determining the response matrix of a liquid scintillation detector. The response matrix can be used in conjunction with neutron unfolding codes to determine the spectrum of the incident neutron field on the basis of the pulse height response measured by the scintillator. Knowledge of the neutron spectrum is highly desirable and cannot be obtained with the traditionally used thermal detectors. The analysis presented includes Monte Carlo simulations of the response matrix, which are compared to the measured response matrix. The simulations are performed with the MCNP-PoliMi code, which models the detector response by taking into account the light output of neutron interactions on hydrogen and carbon nuclei present in the scintillator. We also present some preliminary approaches to the neutron spectrum unfolding problem.

## INTRODUCTION

Neutron measurements, both passive and active, are vital to a wide range of applications in nuclear nonproliferation, international safeguards, nuclear material control and accountability, national security, and counter-terrorism programs. Many current neutron measurement technologies employ thermal neutron detectors, e.g., helium-3 counters, to sense neutrons emitted by fissile materials. However, since these detectors sense only thermal neutrons, the technologies employing them either (1) measure only the thermal neutrons emitted by fissile material configurations or (2) thermalize neutrons before they are detected using hydrogenous materials such as polyethylene. As an alternative to thermal neutron sensors, liquid scintillators that sense fast neutrons and gamma rays can provide the same capabilities for the measurement of mass and multiplication, and can be further applied to measure quantities related to the time decay of fission chain populations. Recent studies [1] have shown that the measurement of neutron spectra can increase the sensitivity of assays performed on nuclear materials. Neutron spectrum unfolding with organic scintillators requires the knowledge of the neutron response matrix, which links the neutron energy with the pulse heights.

## MEASUREMENT OF THE RESPONSE MATRIX

The measurement of the response matrix of the liquid scintillator was performed using a timed Cf-252 spontaneous fission neutron and gamma ray source [2]. The time-of-flight method was used to discriminate neutrons from gamma rays and to determine the neutron energy. In the experiment, the Cf-252 source was placed at a 1 meter distance from the liquid scintillator. The scintillator was a Bicron – BC 501 cylindrical cell having diameter 11.6 cm and thickness 7.5 cm. The data acquisition was performed using a custom-built Matlab program running on a Tektronix TDS-5104 digital oscilloscope. The use of the Matlab Instrument Control Toolbox allowed a totally automated data collection process.

---

\* On research assignment at Oak Ridge National Laboratory

Neutron energies and corresponding pulse heights were stored to build the scintillator's response matrix. The neutron energy was collected in 0.1 MeV bins, within the range 0.5 to 9 MeV (this corresponds to a flight time of 25 to 80 ns, approximately). The pulse heights were collected in 0.05 V bins, in the range 0 to 5.0 V. A total of approximately 100,000 pulses were analyzed.

Figure 1 shows the measured response matrix for the liquid scintillator. The measured data were not normalized, so the response matrix has a larger contribution of low-energy neutrons (up to 2.5 MeV) when compared to that of high-energy neutrons. This is consistent with the Cf-252 neutron spectrum.

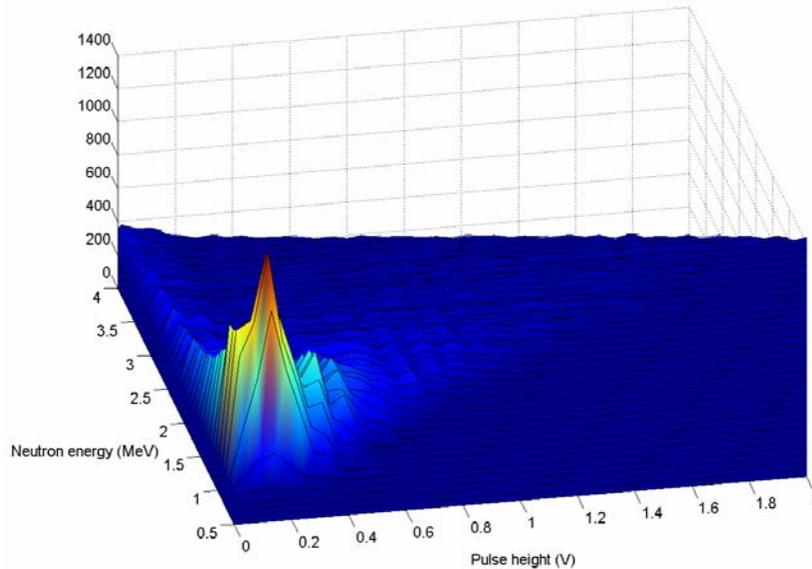


Figure 1. Measured pulse height distribution (V) of pulses registered by the liquid scintillator for varying neutron energies (MeV).

## UNFOLDING CODE

The proton-recoil pulse-height data are unfolded using the FORIST spectrum unfolding code [3]. FORIST (**F**erdor with **O**ptimized **R**esolution using an **I**terative **S**moother **T**echnique) is a modification of the FERDOR code [4]. Because the response matrix used in the method includes the resolution of the spectrometer, the elements of the solution vector have large statistical errors and require smoothing. The smoothing functions are determined iteratively to optimize the energy resolution.

Our results are unfolded using the Illinois neutron response matrix [5], which is supplied with the FORIST code. This matrix is based on the measurements of Verbinski et al. [6] for a 4.60x4.65 cm liquid organic scintillator. The scintillator material is NE-213, which is identical to BC 501. The pulse height is given in light units, where one light unit is defined as the position of the half-height of the Compton edge produced in NE-213 by the 1.28 MeV Na-22 gamma rays. The Illinois response matrix, shown in Figure 2, is similar to our measured response matrix, shown in Figure 1.

## SIMULATIONS

The Monte Carlo code MCNP-PoliMi [7] was used to simulate the neutron interactions with the liquid scintillator. At each neutron interaction inside the scintillator, the information on the collision is printed in the data output file. This information is then post-processed using a specifically

designed post-processing code. In this code, the energy deposited is converted into light output by taking into account the collision nucleus (carbon or hydrogen). The conversion to light output is performed on the basis of previous studies that provided the light output curves for liquid and plastic scintillators [8, 9].

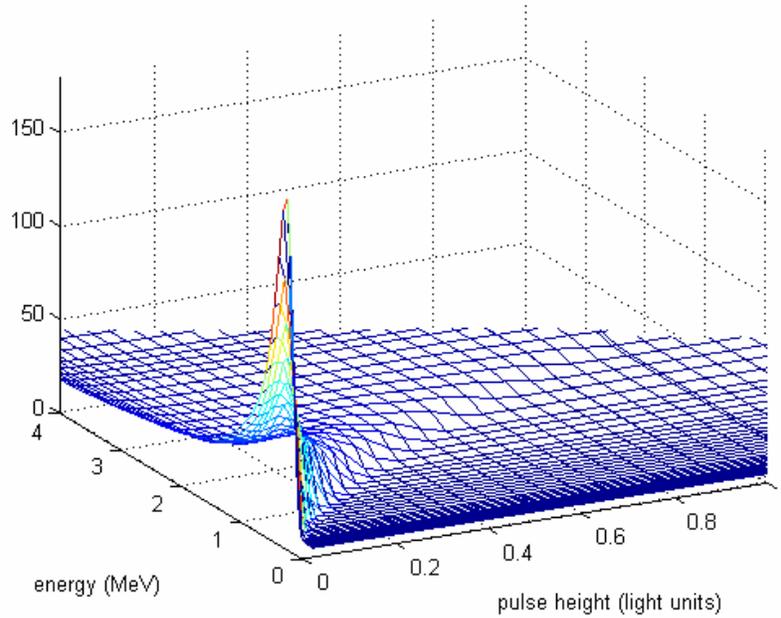


Figure 2. The Illinois response matrix. The displayed data start from a pulse height of 0.05 light units. One light unit corresponds approximately to a pulse height of 2 V for the liquid scintillator used in our measurements, so that this figure can be compared to the measured response matrix shown in Figure 3.

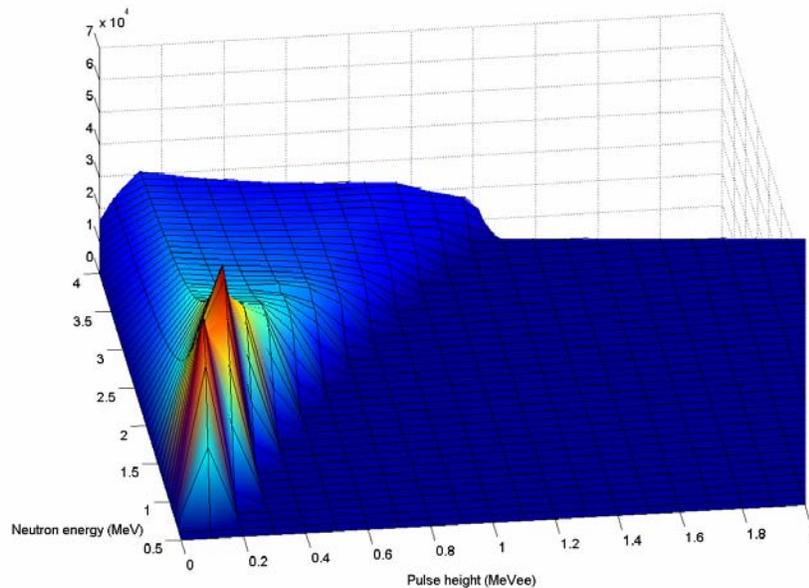


Figure 3. Results of MCNP-PoliMi simulations of pulse height distribution of pulses registered by the liquid scintillator for varying neutron energies (MeV).

Comparison of the simulation shown in Figure 3 with the experimental result shown in Figure 1 requires a conversion of pulse height from volts to MeVee (MeV electron equivalent). This conversion can be performed by using a number of reference gamma ray sources to find the correlation between electron-equivalent energy deposited and pulse height [4]. The correlation depends on the detector settings and should be determined on a case by case basis.

Figure 4 shows the measured and simulated pulse height distributions for various neutron energies. The simulation results show a clean response function (Figure 4(b)). The experimental results (Figure 4(a)) have the same qualitative trend. A longer measurement would result in a more converged signature. The measured data for neutron energies equal to 3 and 4 MeV show a peak, which appears at low pulse heights.

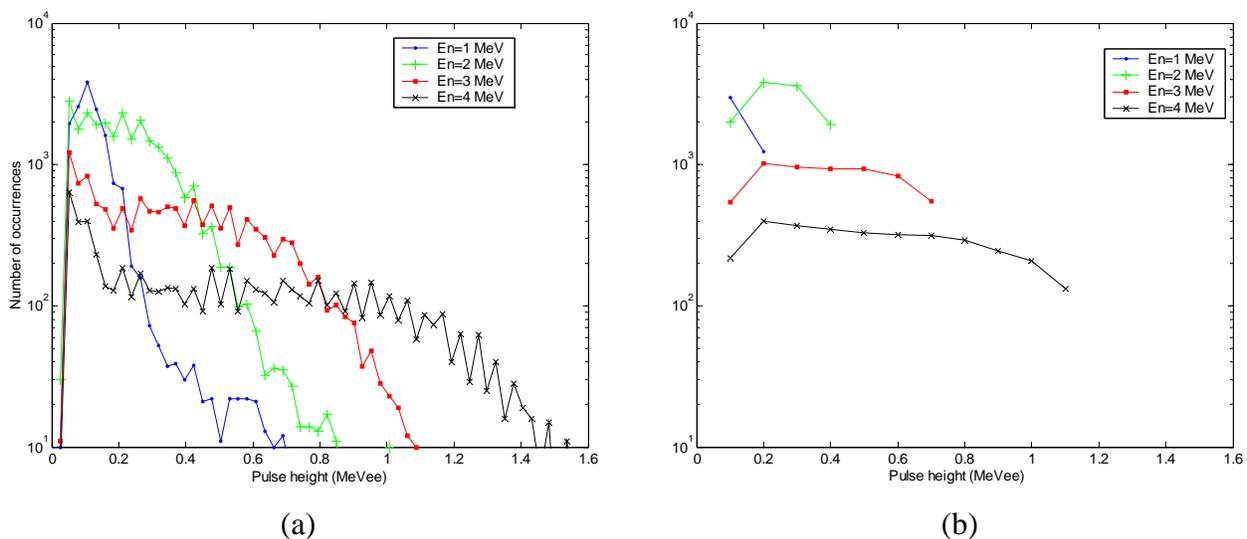


Figure 4. Results of (a) measurement and (b) MCNP-PoliMi simulation of pulse height distribution of pulses registered by the liquid scintillator for various neutron energies.

Figure 5(a) shows the simulated pulse height distribution generated in the detector by a source of 4 MeV neutrons and a source of 14 MeV neutrons. The neutron spectrum was unfolded with the FORIST code, using the Illinois neutron response matrix, and the result is shown in Figure 5(b). The resulting neutron peaks are well resolved. Their energy are approximately 3 MeV and 15 MeV. We could probably obtain a better agreement with the incident neutron energies by performing a more accurate gain calibration. The area of the peaks in the unfolded spectrum is related to the number of particles detected at each energy. In the simulation, the number of 14 MeV neutrons detected was 61% of the number of 4 MeV neutrons detected, because high energy neutrons are more likely to pass undetected through the scintillator. The area of the 14 MeV peak is approximately 67% of the area of the 4 MeV peak.

Figure 6(a) shows the simulated pulse height distribution generated in the detector by a Cf-252 source. Only the pulses generated by neutron interactions are taken into account. The unfolded neutron spectrum is shown in Figure 6(b). The unfolded spectrum is affected by large errors for neutron energies less than 1 MeV. Previous measurements of the Cf-252 fast neutron spectrum [4, 10] were found to be adequately described by a Maxwellian distribution with a temperature of 1.4

MeV. This Maxwellian distribution is plotted in Figure 7 together with the unfolded neutron spectrum.

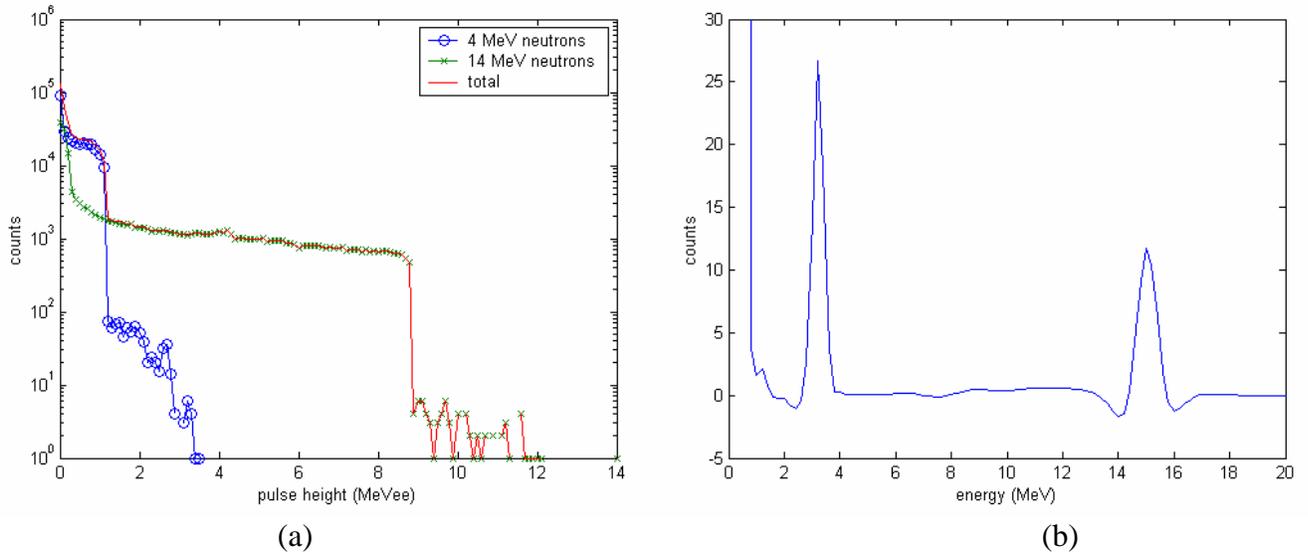


Figure 5. Simulation of 4 MeV and 14 MeV neutrons. (a) Pulse height distribution. (b) Unfolded spectrum.

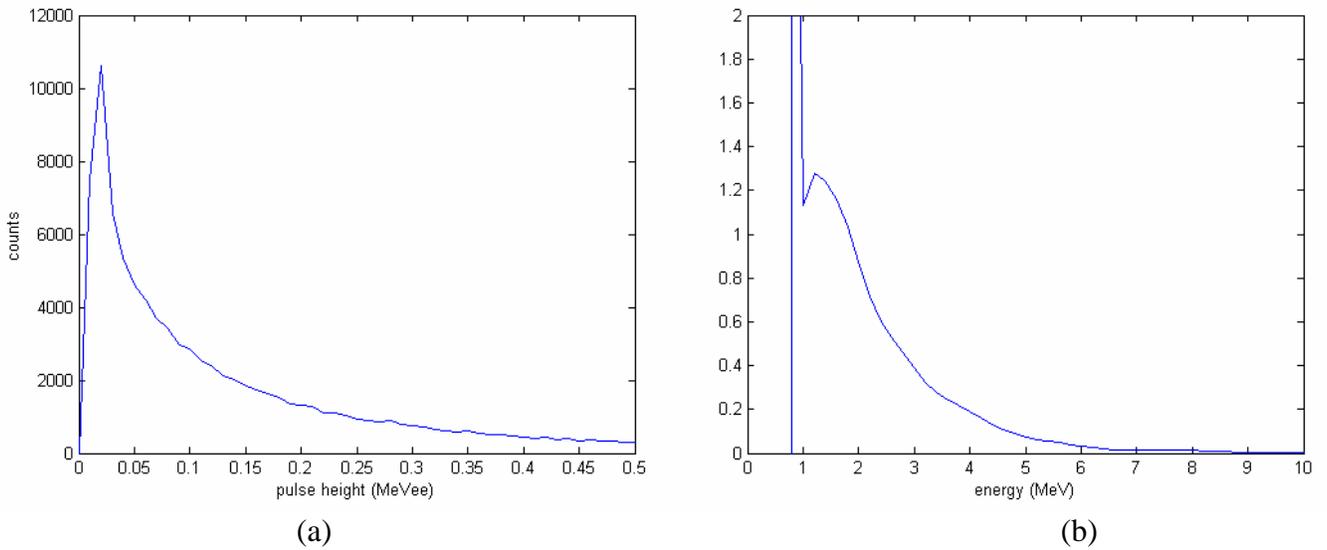


Figure 6. Simulation of Cf-252 source. (a) Pulse height distribution. (b) Unfolded spectrum.

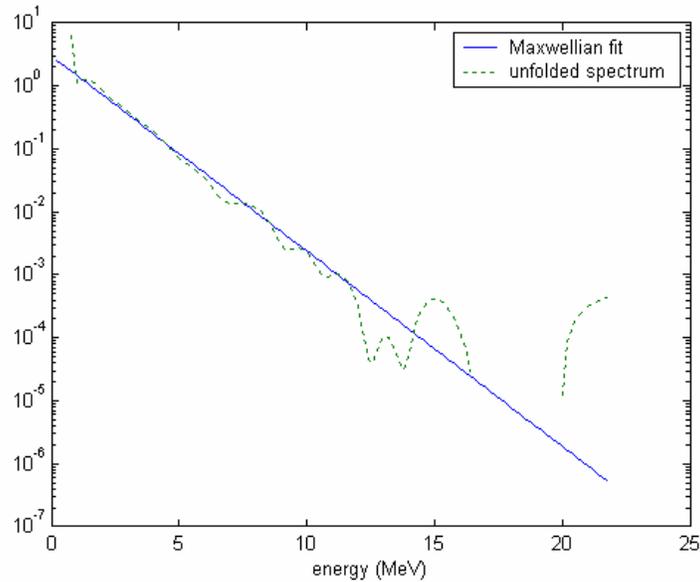


Figure 7. Unfolded neutron energy spectrum from simulation (Cf-252 source), compared with a Maxwellian distribution with  $kT=1.4\text{MeV}$

### MEASUREMENT

Figure 8(a) shows the measured neutron pulse height spectrum from a Cf-252 source. Since the unfolding code requires more pulse height bins than those used in our measurement, we fitted the measured pulse height distribution with a 10<sup>th</sup> degree polynomial. Figure 8(b) shows the unfolded neutron spectrum. The spectrum is not reliable at low energies (below 1 MeV), where the solution is affected by very large errors.

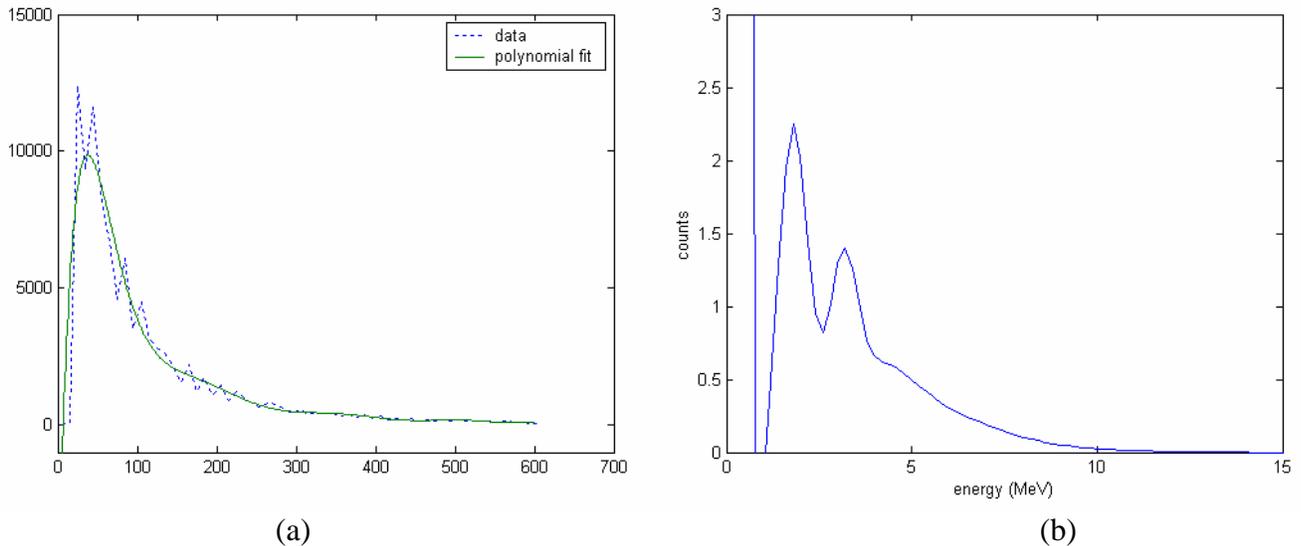


Figure 8. (a) Measured neutron pulse height distribution (Cf-252 source). (b) Unfolded spectrum.

The unfolded spectrum is plotted in Figure 9 together with the Maxwellian distribution. There is reasonable agreement between the two curves between 1 and 13 MeV approximately. For higher

energies, we could probably obtain a better agreement by performing longer measurements, so that more high energy neutrons are detected.

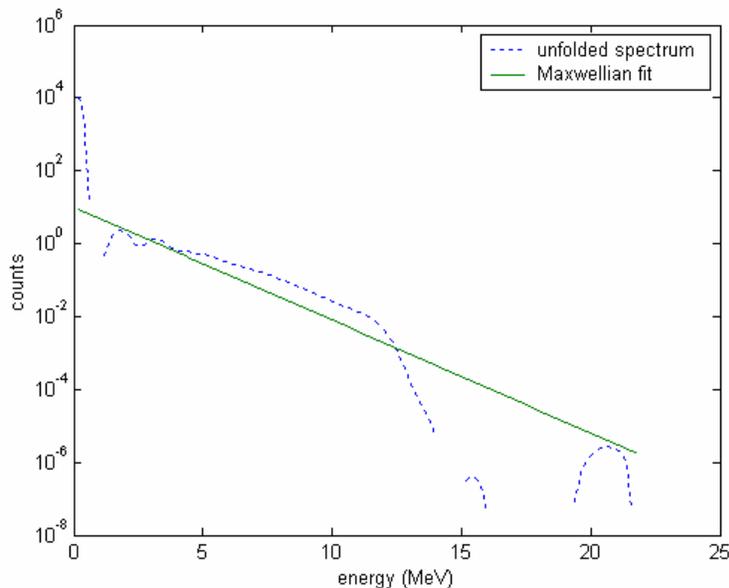


Figure 9. Unfolded neutron energy spectrum from measurement (Cf-252 source), compared with a Maxwellian distribution with  $kT=1.4\text{MeV}$

## CONCLUSIONS

We presented the results of experiments and Monte Carlo simulations aimed at determining the neutron response matrix for a liquid scintillation detector. We found reasonable agreement between the measurement and the simulation of the pulse height distributions for neutron energies from 1 to 4 MeV. Preliminary attempts to determine the neutron spectrum from the pulse height distribution were also presented. Reasonable agreement was obtained with simulated pulse height spectra of monoenergetic neutron sources, in the energy range from 3 to 14 MeV. Good agreement was also obtained using the pulse height distribution that is obtained by summing the response of two monoenergetic neutron lines. Unfolding of the results of measurements and simulations using a Cf-252 neutron spectrum was affected by large errors that need to be explained by future work.

## REFERENCES

1. J.A. Mullens, J.D. Edwards, and S.A. Pozzi, "Analysis of Scintillator Pulse-Height for Nuclear Materials Identification," Institute of Nuclear Materials Management 45th annual meeting, July 18-22, 2004, Orlando, Florida.
2. J.T. Mihalcz, Use of Cf-252 as a Randomly Pulsed Neutron Source for Prompt Neutron Decay Measurements, Y-DR-41, UCC-ND Oak Ridge Y-12 Plant (1970).
3. Radiation Shielding Information Center, Oak Ridge National Laboratory, PSR-92
4. Radiation Shielding Information Center, Oak Ridge National Laboratory, PSR-17
5. R.H. Johnson, D.T. Ingersoll, B.W. Wehring, and J.J. Dorning, "NE-212, Neutron Spectrometry System for Measurements from 1.0 to 20 MeV", Nucl. Instr. And Meth. 145 (1977) 337-346.

6. V.V. Verbinski, W.R. Burrus, T.A. Love, W. Zobel, N.W. Hill and R. Textor, Nucl. Instr. And Meth. 67 (1969) 181.
7. S.A. Pozzi, E. Padovani, and M. Marseguerra, "MCNP-PoliMi: A Monte Carlo Code for Correlation Measurements," Nuclear Instruments and Methods in Physics Research A, 513/3 pp. 550-558, 2003.
8. S.A. Pozzi, J.A. Mullens, and J.T. Mihalczo, "Analysis of Neutron and Photon Detection Position for the Calibration of Plastic (BC-420) and Liquid (BC-501) Scintillators," Nuclear Instruments and Methods in Physics Research Section A, in press.
9. J.B. Czirr, D.R. Nygren, and C.D. Zafiratos, "Calibration and Performance of a Neutron Time of Flight Detector," Nuclear Instruments and Methods 31 (1964) 226-232.
10. D. Stuenkel, J.P. Holloway, and G.F. Knoll, "Neutron Spectrum Unfolding Using a Modified Truncated Singular Value Decomposition Method," Nuclear Science and Engineering, 132 pp. 261-272, 1999.