Neutron Spectrometry Using a ^{7}Li Enriched CLYC Scintillation Detector

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Workshops on Radiation Monitoring for the International Space Station

20th WRMISS, Cologne, Germany. September 8-10, 2015.

Outline

- Introduction
- Methodology
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  – Radiation Detection System
  – Experimental Investigation
- Results
- Discussion
- Conclusion
- Future Work
- Acknowledgements

Introduction

Neutron Detection - CLYC

$Cs_2LiYCl_6:Ce$ Scintillator

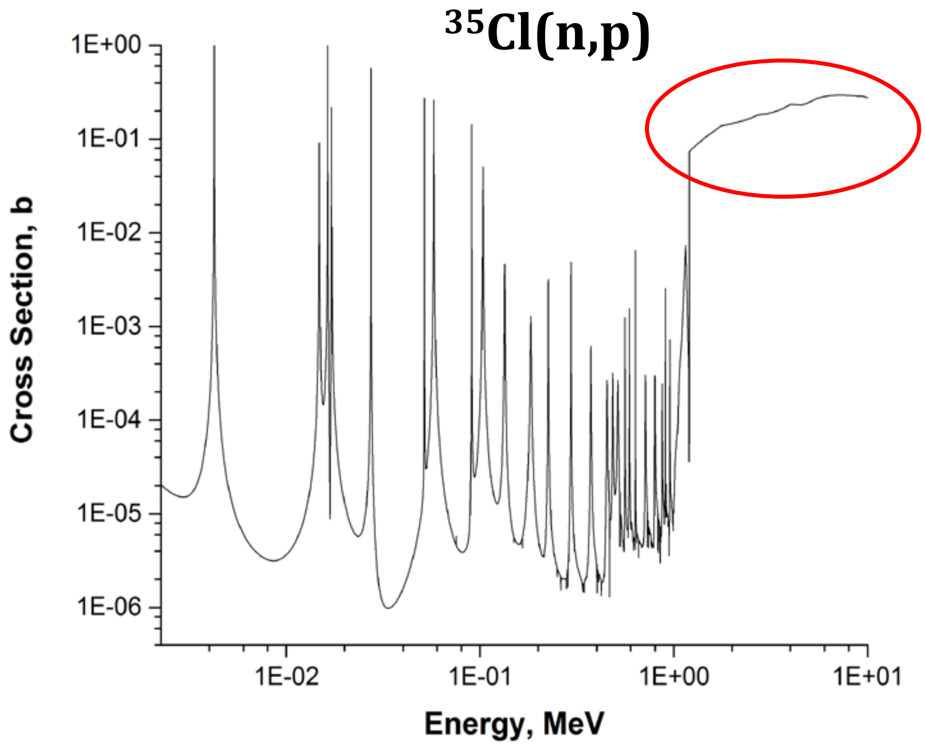


Figure 1: ENDF/B-VII.1 $^{35}Cl(n,p)$ cross section

Introduction

Cs_2LiYCl_6:Ce Scintillator

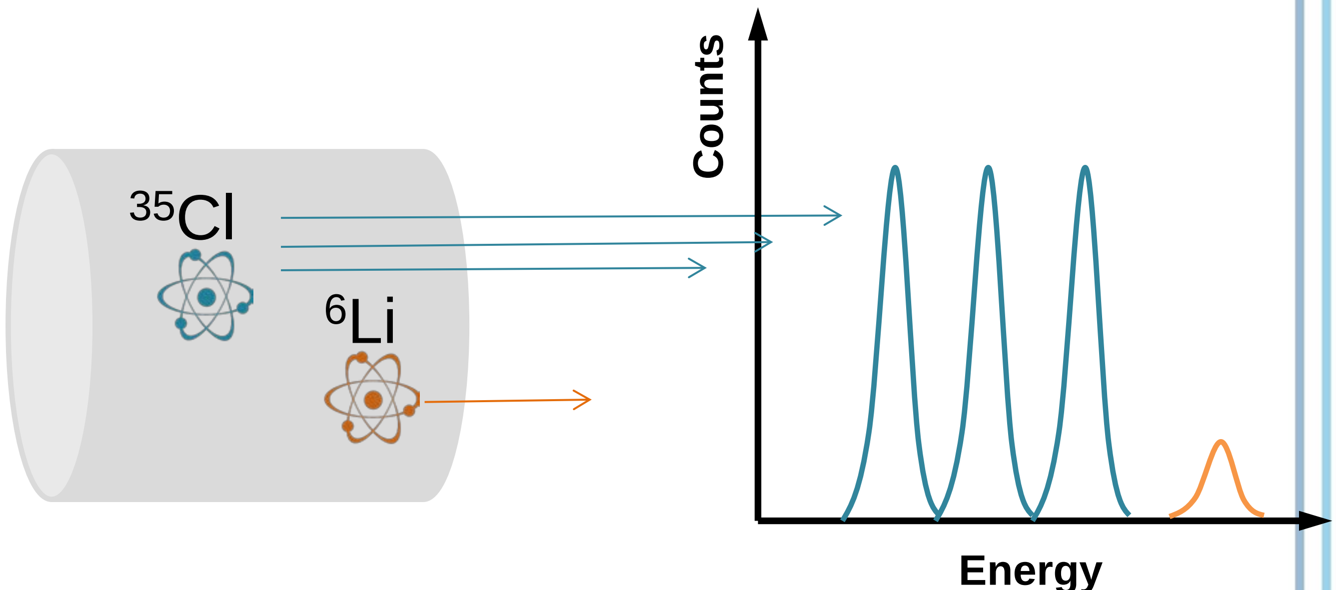


Figure 2: CLYC spectra

$${}^{1}_{0}n + {}^{6}_{3}Li \rightarrow {}^{3}_{1}H + {}^{4}_{2}He \qquad Q = 4.78\ \text{MeV}$$

$${}^{1}_{0}n + {}^{35}_{17}Cl \rightarrow {}^{35}_{16}S + {}^{1}_{1}p \qquad Q = 0.615\ \text{MeV}$$

^{6}Li reaction (n,α) dominates so 99% ^{7}Li enriched CLYC is used

Methodology

MCNP Simulation

- MCNPX radiation transport code
- 99% ^{7}Li enriched CLYC (materials and geometry)
- pulse height spectra for mono-energetic neutron sources
- Tracked: n, alpha, proton, T, D, electrons and gamma

Source:

- Mono-energetic Neutrons
- Point source
- 10^9 source particles

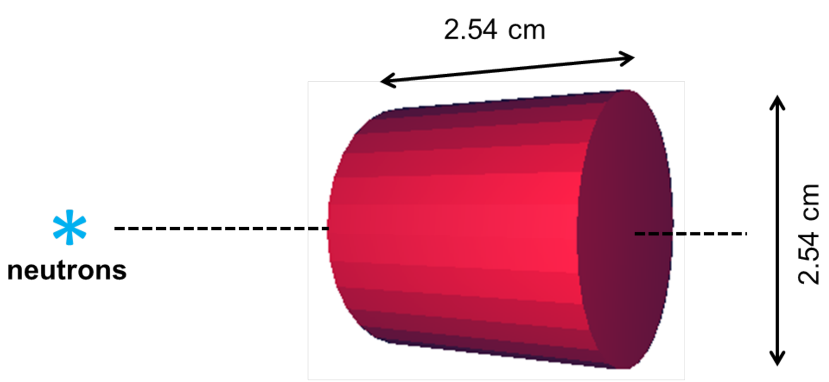


Figure 3: MCNPX model of Cs_2LiYCl_6:Ce detector for neutron simulations

Methodology

Radiation Detection System

The radiation Detector consists of:

- 99% ^{7}Li enriched CLYC from RMD
- Hamamatsu R3998-02 PMT
- MCA (Bridgeport eMorpho)

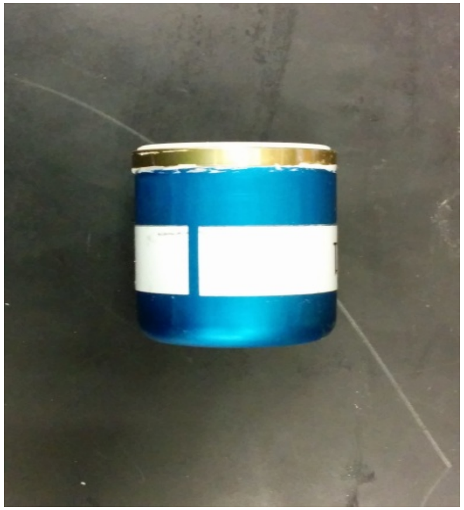
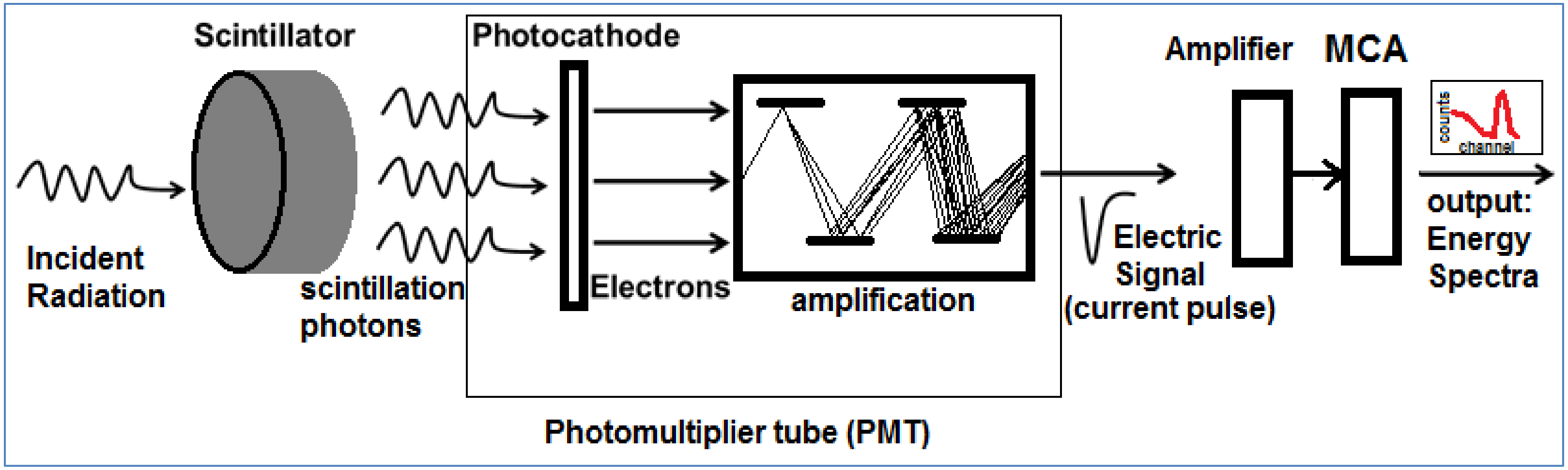


Figure 4: Cs_2LiYCl_6:Ce scintillator



Methodology

Experimental Investigation

UOIT neutron generator

- Mono energetic neutrons
  - 2.5 MeV

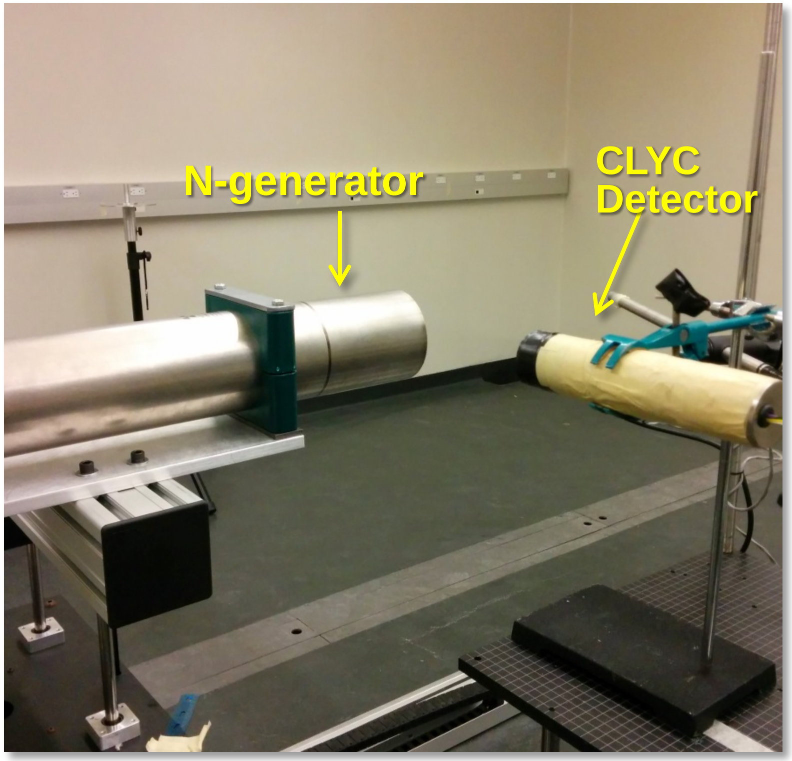


Figure 5: UOIT neutron source

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{1}_{0}n + ^{3}_{2}He$$

Spectrumtechniques rss-8 gamma button sources

Methodology

Experimental Investigation

KN Van De Graaff accelerator at McMaster University, Canada.
300 keV to 4 MeV neutrons

- Mono energetic neutrons
  - 2.67 MeV
  - 3.57 MeV
  - 4.0 MeV

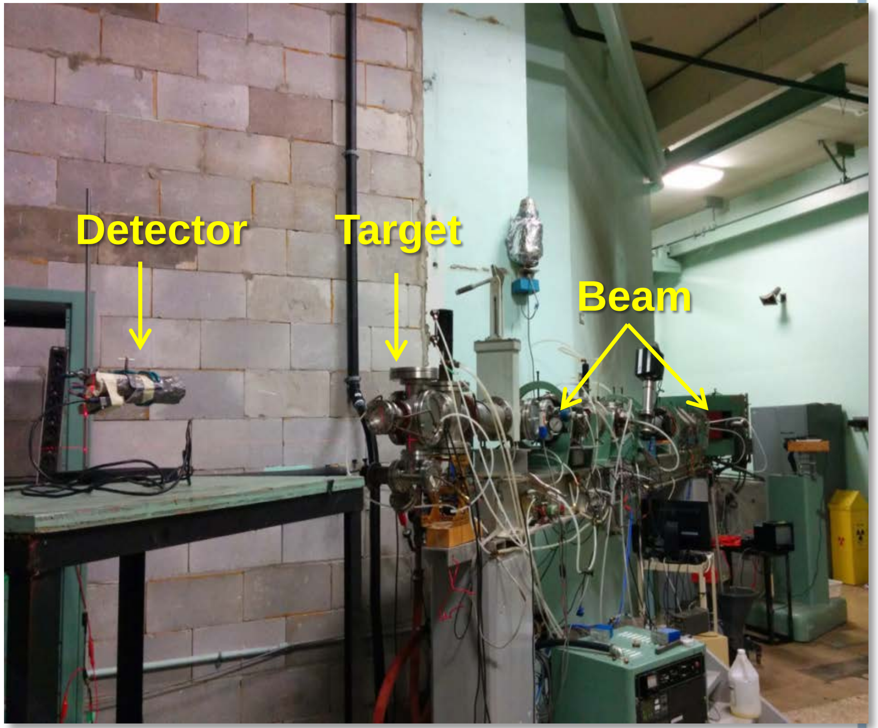


Figure 6: McMaster LINAC

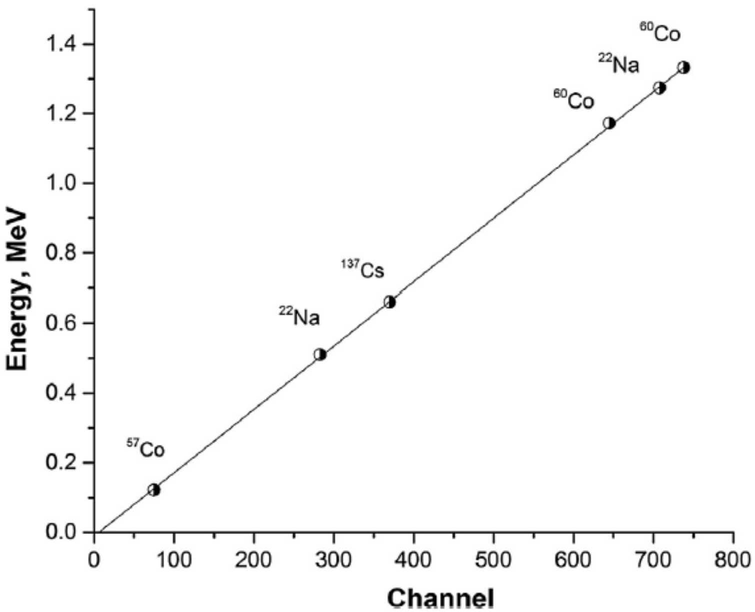
$$ {}^{1}_{1}p + {}^{7}_{3}Li \longrightarrow {}^{1}_{0}n + {}^{7}_{4}Be $$

$$ {}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{1}_{0}n + {}^{3}_{2}He $$

Results

Energy calibration and gamma response

Energy calibration



Gamma peak Resolution

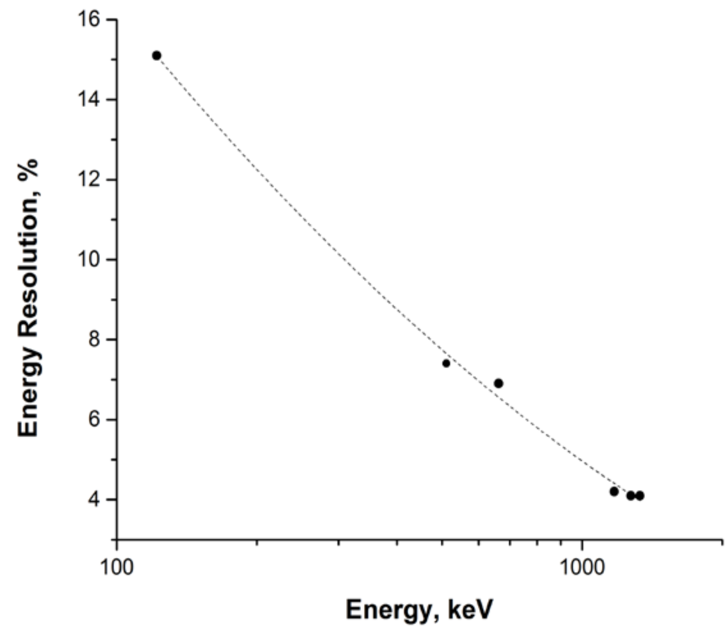


Figure 7: a) CLYC energy calibration, b) CLYC resolution [1]

Results

2.5 MeV neutrons and ^{22}Na button source

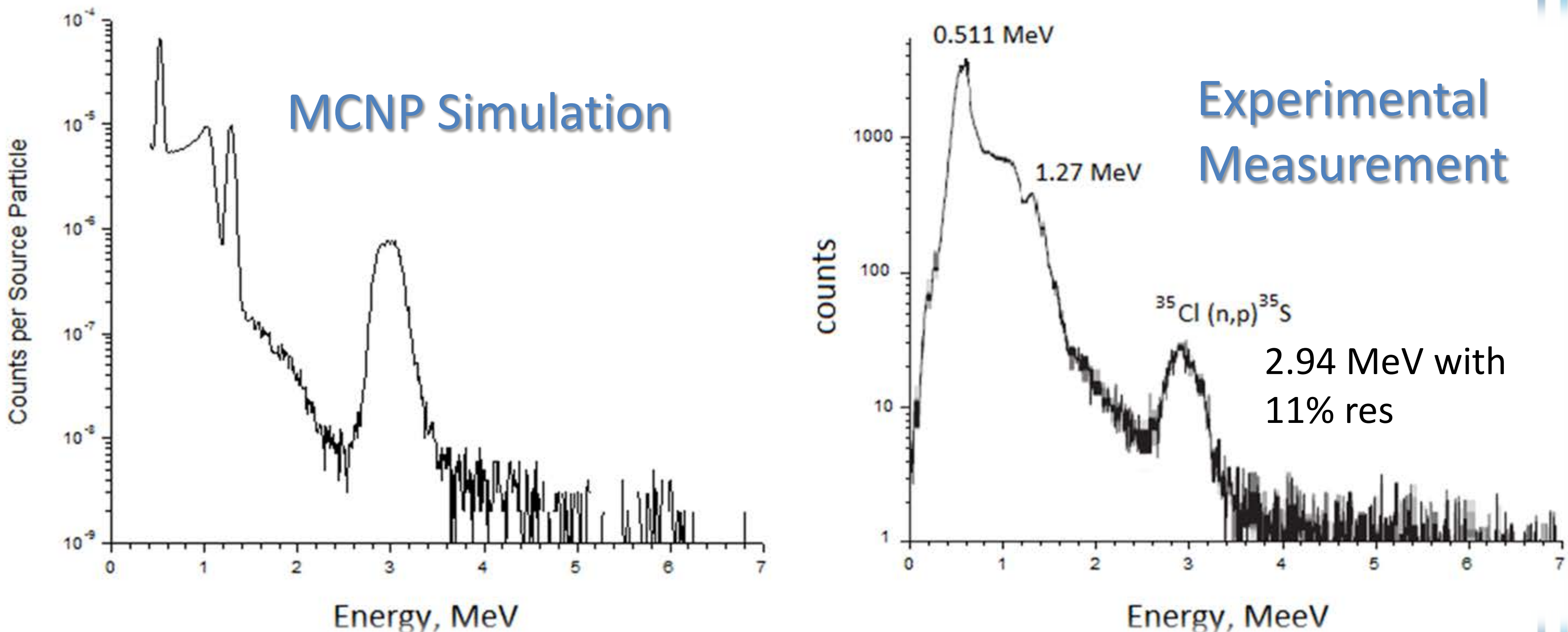


Figure 8: 2.5 MeV neutrons a) MCNP, b) experiment

Results

2.5 MeV neutrons

$${}^{1}_{0}n + {}^{35}_{17}Cl \rightarrow {}^{35}_{16}S + {}^{1}_{1}p$$

Q= 0.615 MeV

Proton energy + ^{35}S recoil energy = 2.5MeV + 0.615 MeV = 3.115 MeV

Proton Energy Spread = 2.809 MeV to 3.114 MeV

- **Energy of the proton depends on angle of emission relative to the direction of the incident neutron**

Proton Peak center at 2.96 MeV with a width of 10.3 %

- **Only the proton contributes to scintillation in the detector so the peak appears centered at the average energy of the proton with a width representing the range of possible proton energies**

Results

2.67, 3.57 and 4.0 MeV neutrons

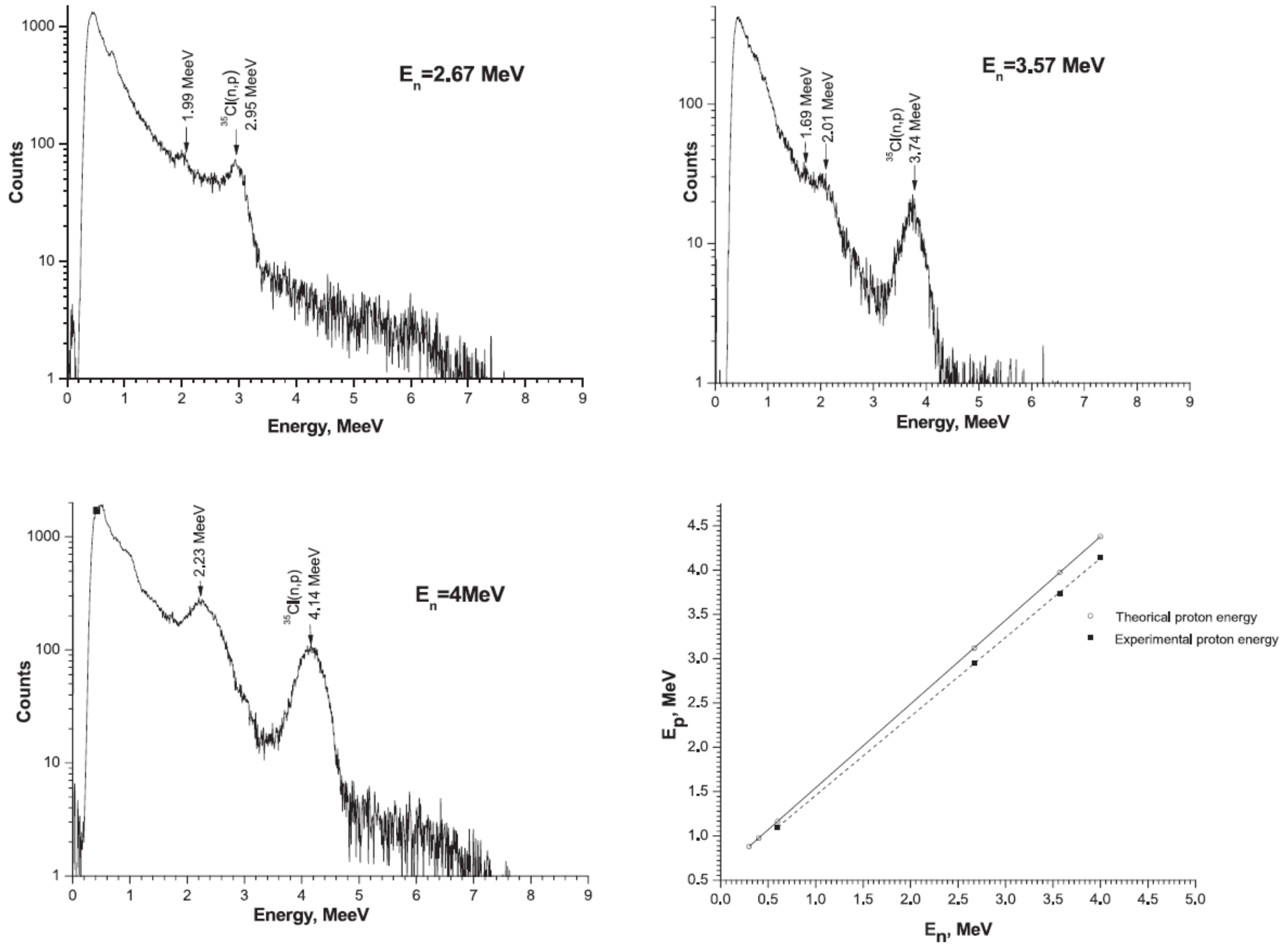
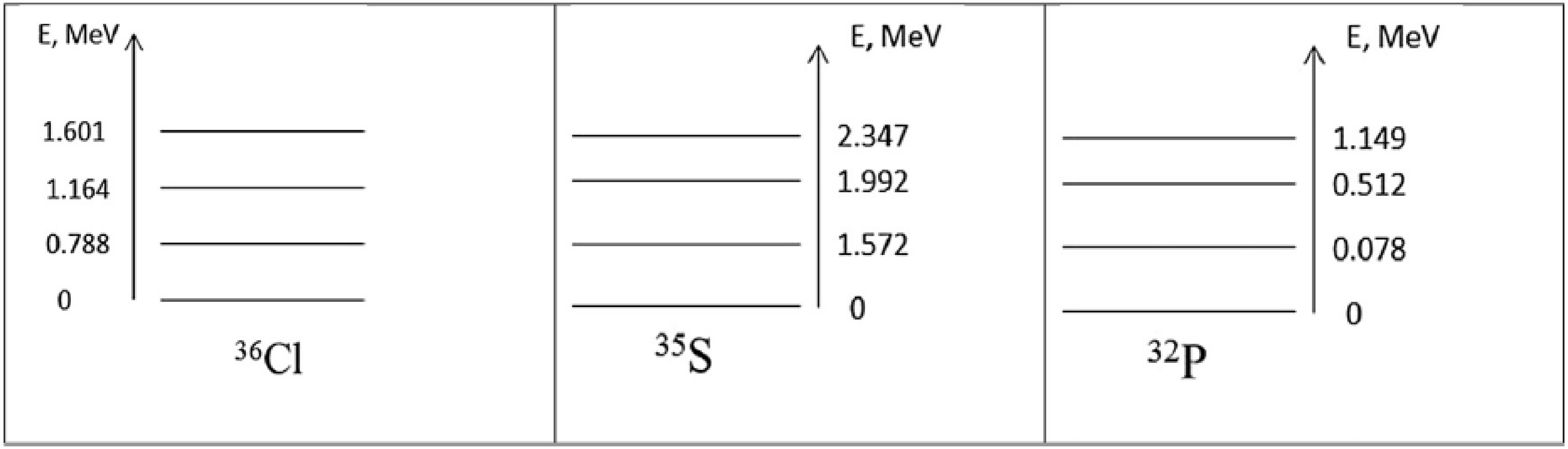


Figure 9: spectra for neutrons a)2.67 MeV, b)3.57 MeV, c) 4 MeV d) linear peak positions (MeeV) [2]

Discussion
Secondary Peaks



Nuclear energy levels of ^{36}Cl ^{35}S and ^{32}P (Tuli et al.,).

Figure 10: Excited state energy levels [3]

Discussion

MCNP Analysis

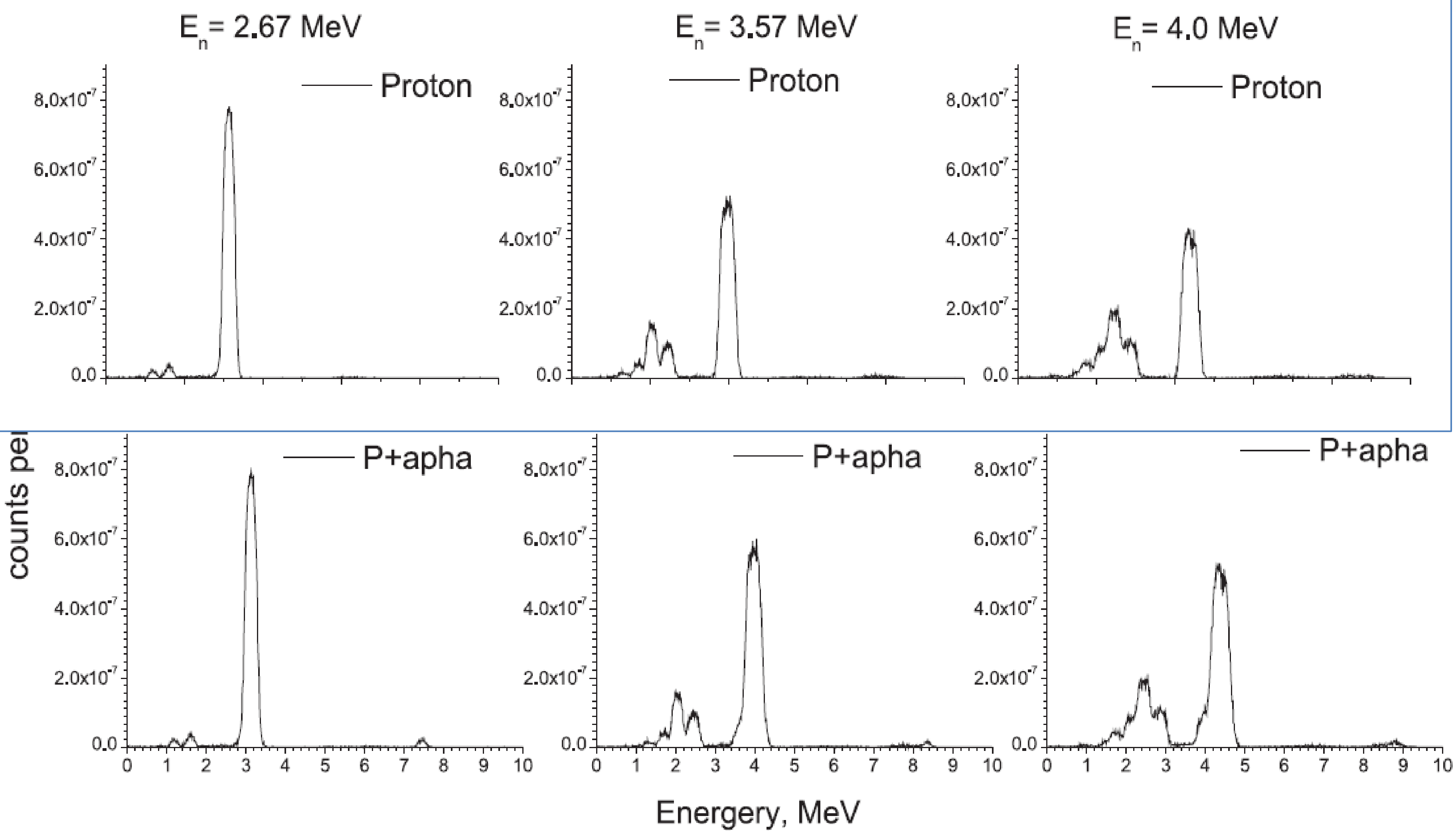
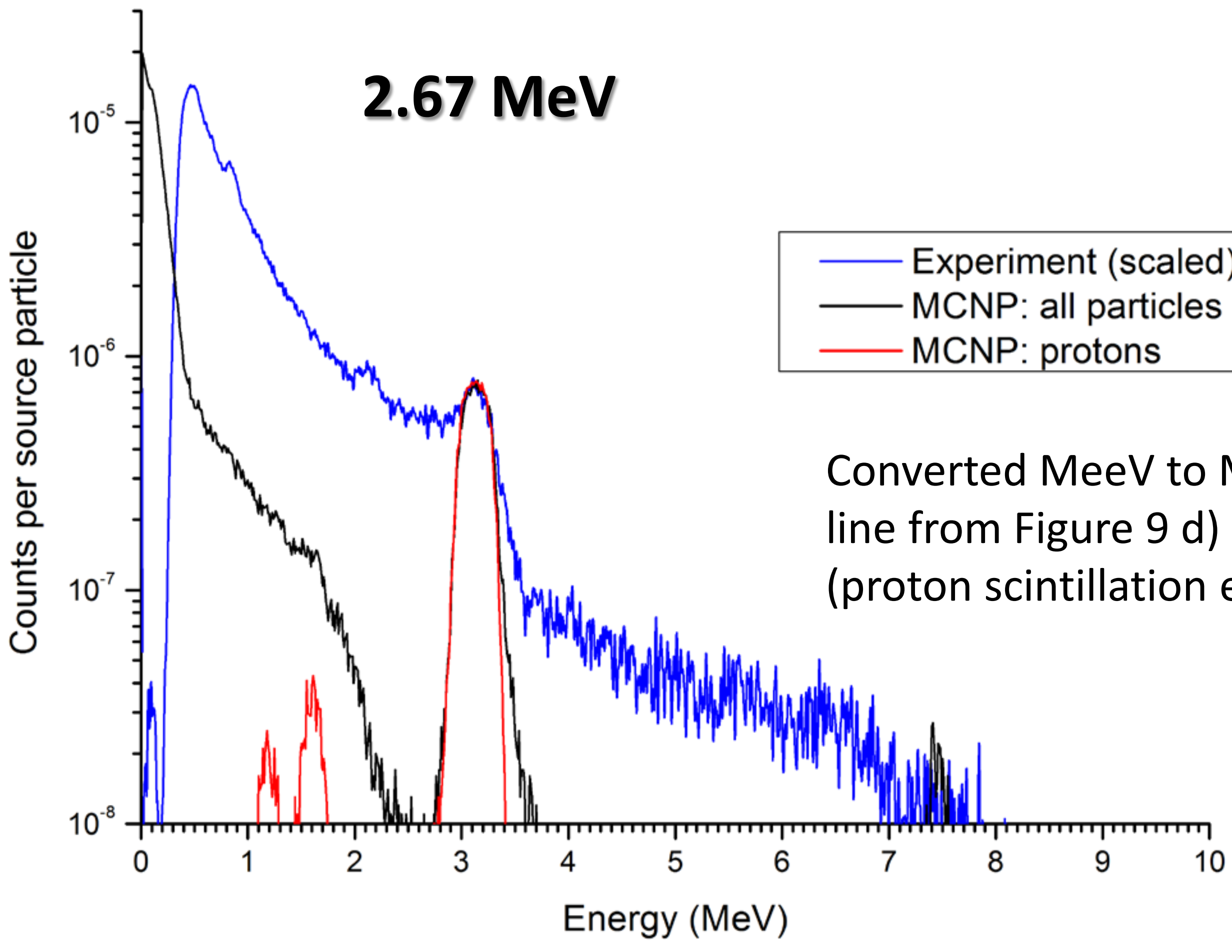


Figure 11: MCNP Simulations for 2.67 MeV, 3.57 MeV and 4 MeV neutrons [2]

Discussion
MCNP Comparison



Converted MeeV to MeV using line from Figure 9 d) (proton scintillation efficiency)

Figure 12: MCNP and experiment for 2.67 MeV neutrons

Discussion
MCNP Comparison

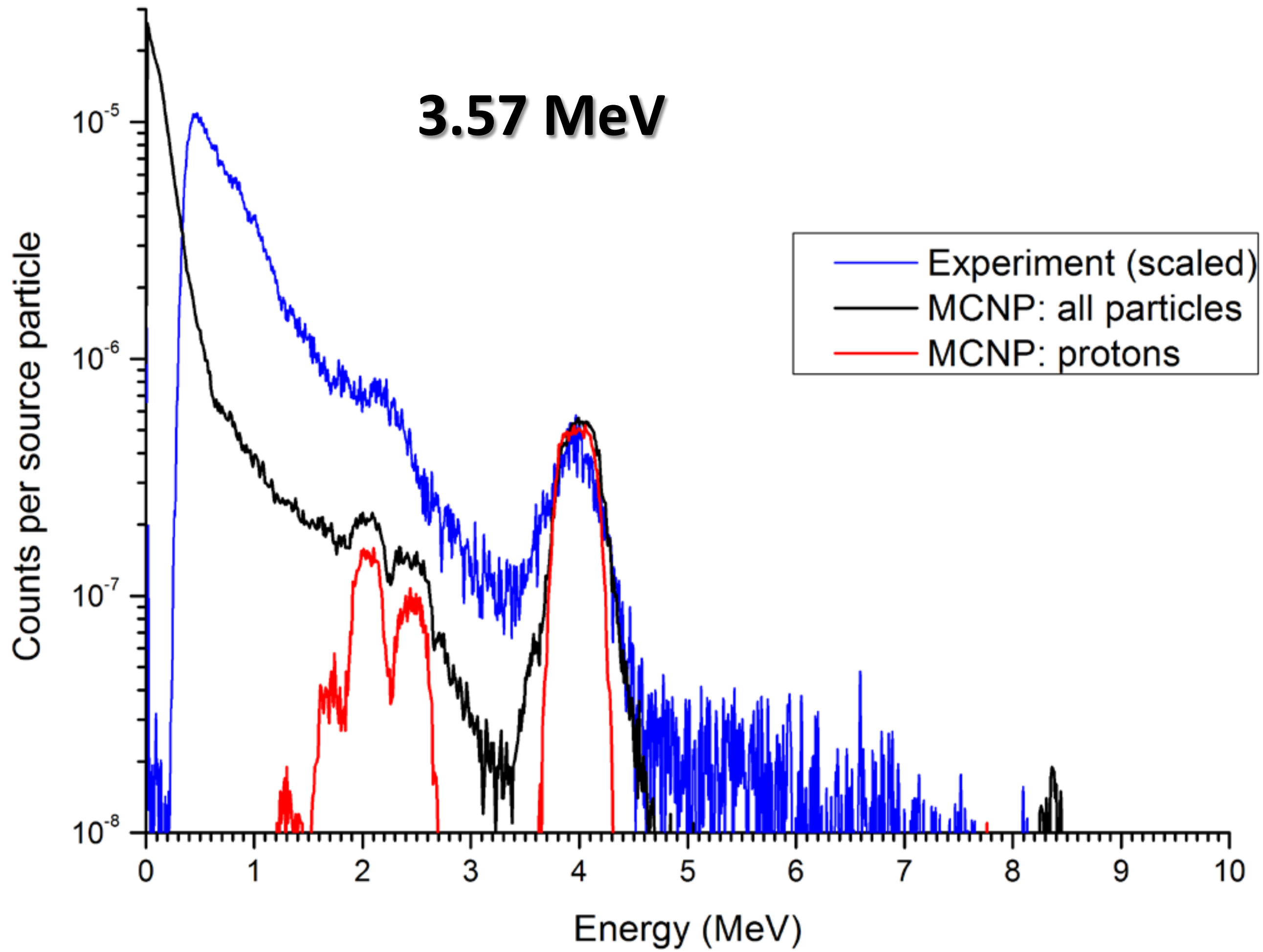


Figure 13: MCNP and experiment for 3.57 MeV neutrons

Discussion
MCNP Comparison

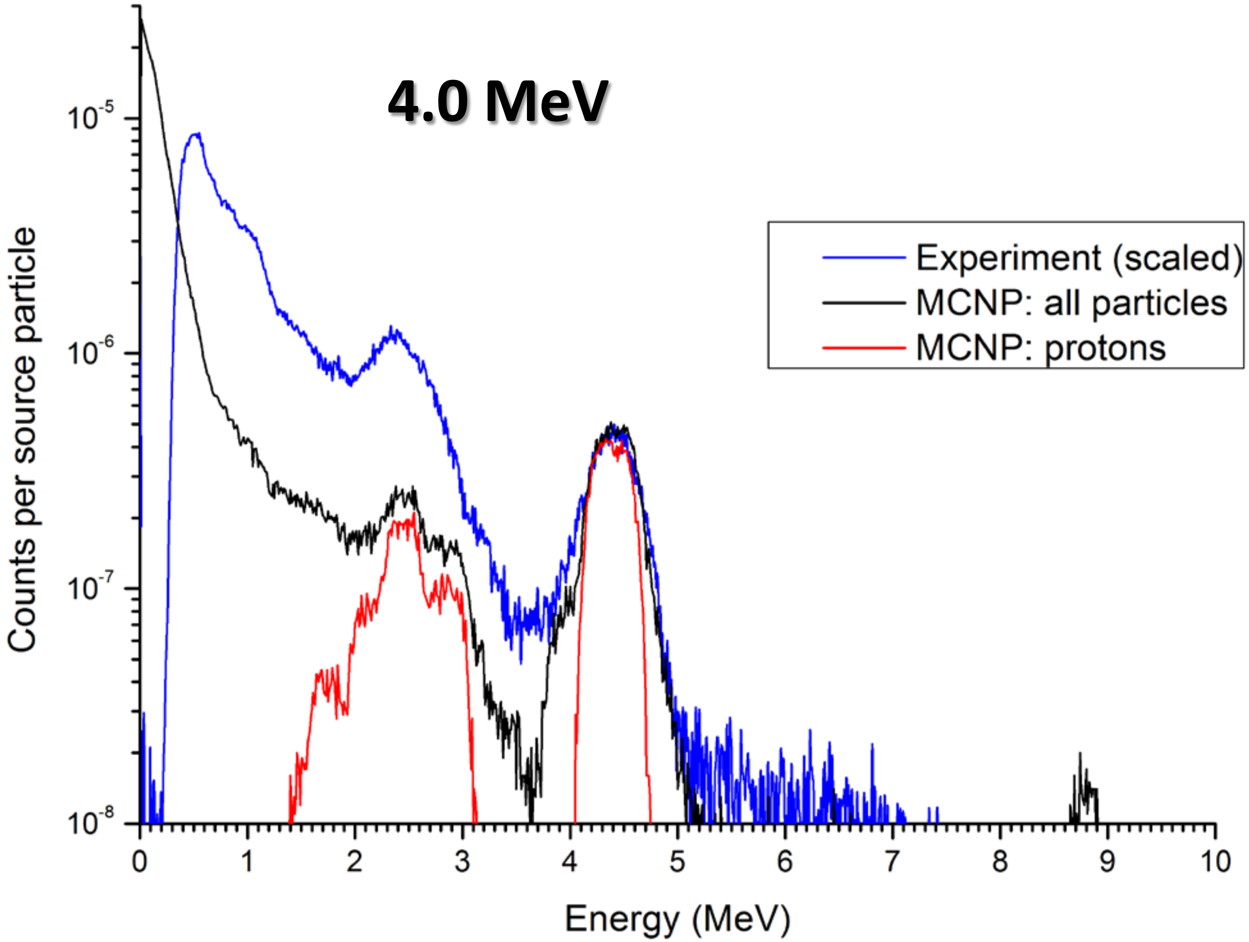
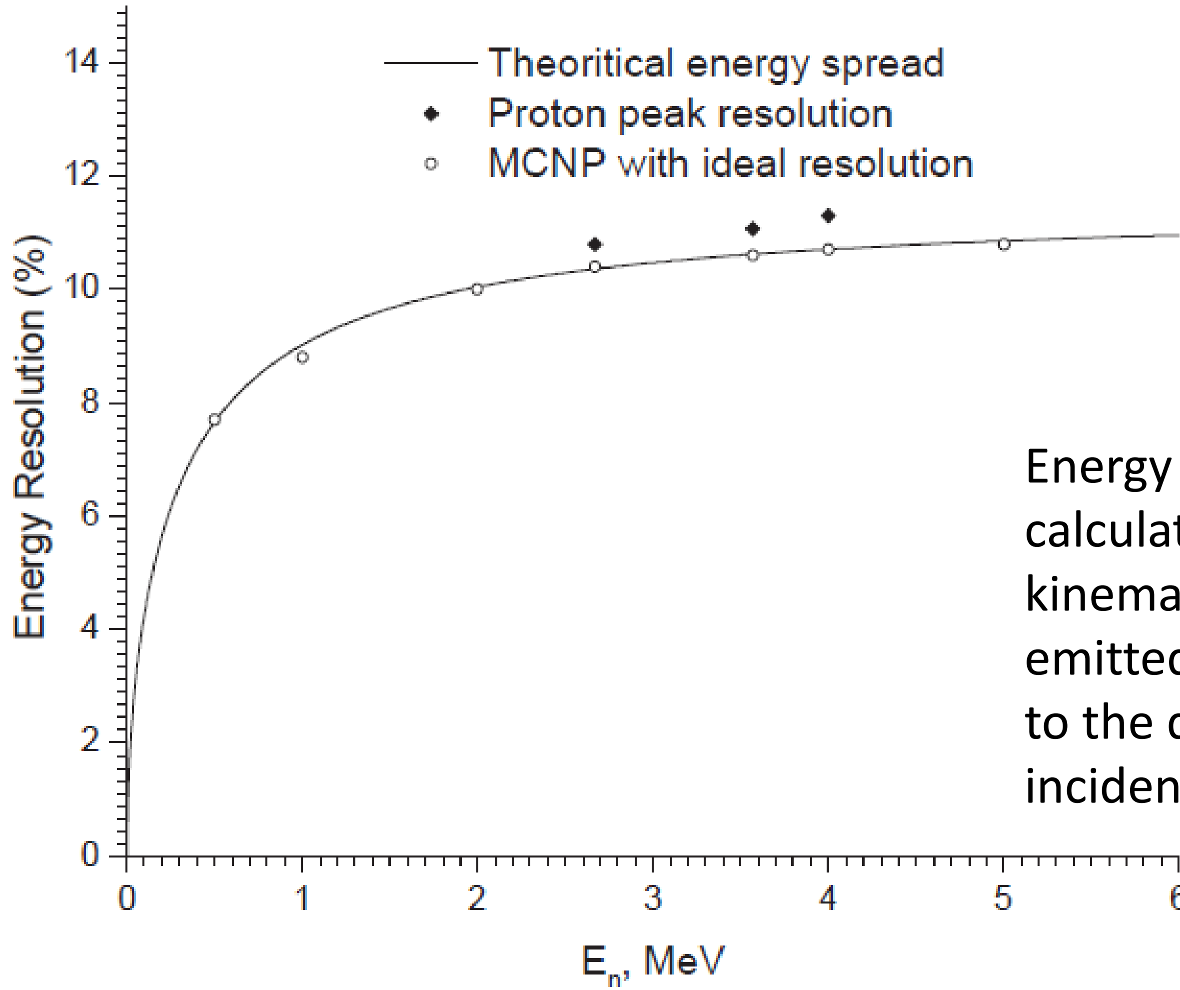


Figure 14: MCNP and experiment for 4 MeV neutrons

Discussion
Proton Peak Resolution



Energy spread calculated from kinematics: angle of emitted proton relative to the direction of the incident neutron

Figure 16: Proton peak resolution [2]

Discussion

MCNP Simulation

0.1 MeV to 5 MeV

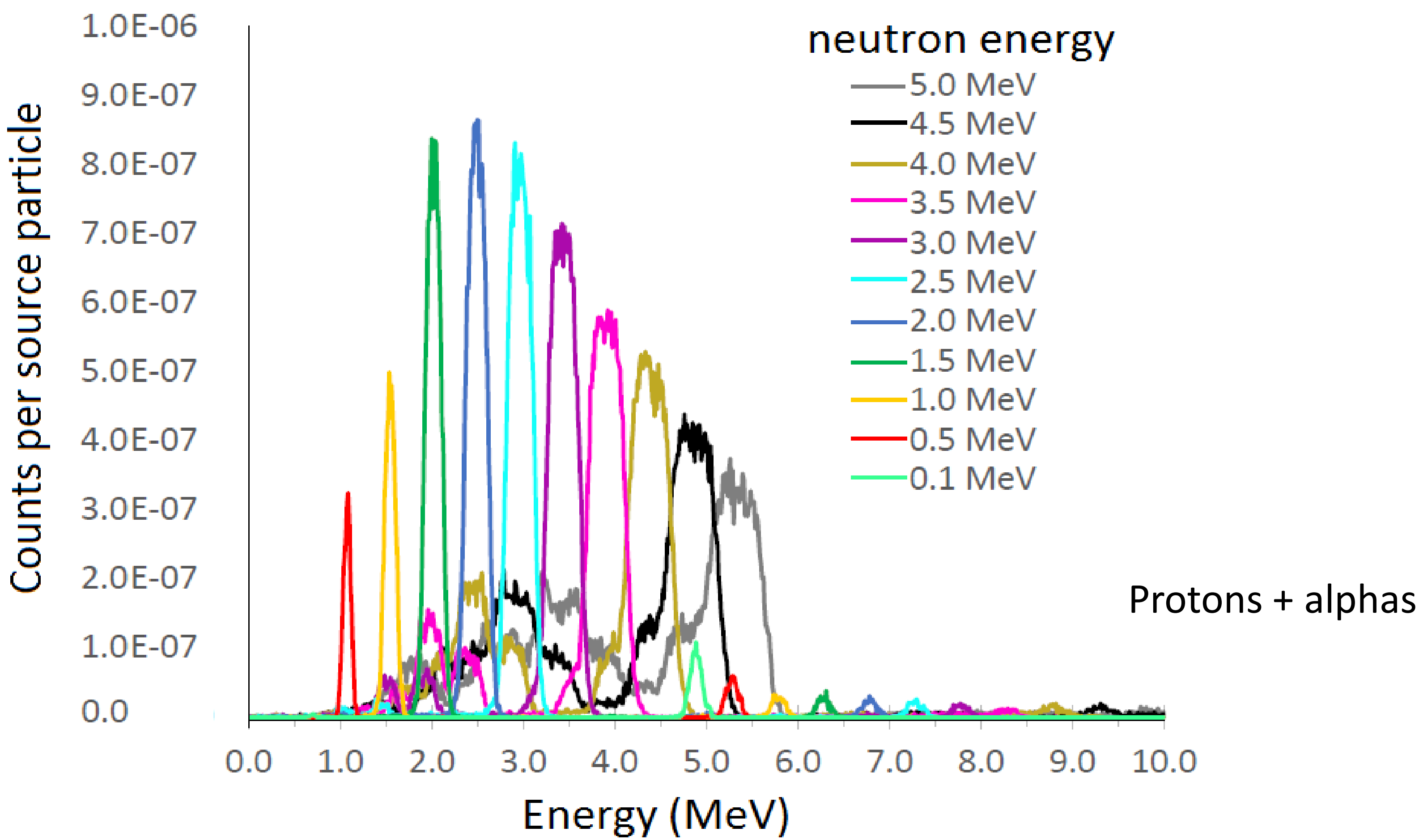
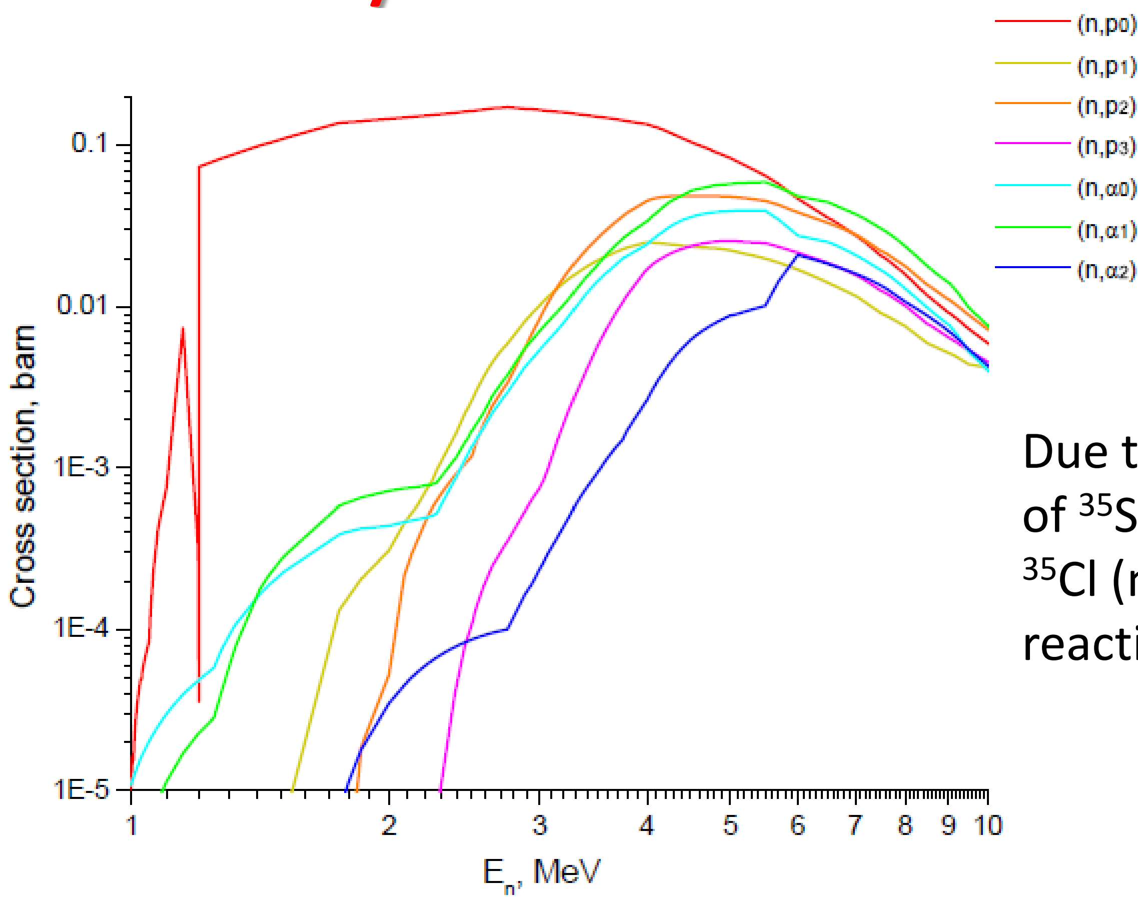


Figure 15: MCNP neutrons (0.1 MeV – 5 MeV)

Discussion
Secondary Peaks



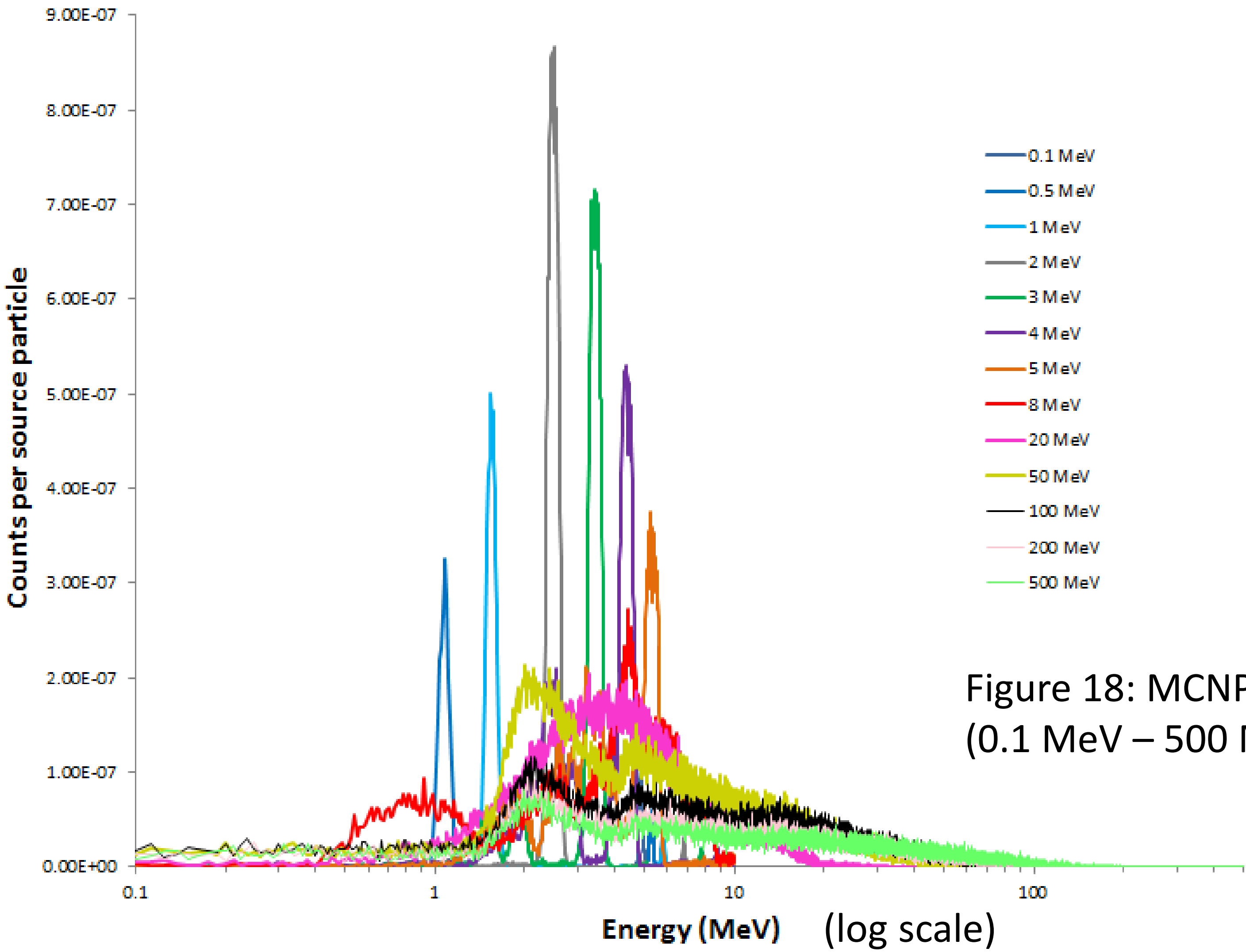
Ground and excited state cross sections of $^{35}Cl(n,\alpha)^{35}S$ and $^{35}Cl(n,p)^{32}P$ (ENDF/B-VII.1, 2014).

Due to excited states of ^{35}S and ^{32}P from ^{35}Cl (n,p) and (n,α) reactions

Figure 17: Excited state cross sections [4]

Discussion

MCNP high energy neutrons



(log scale)

Figure 18: MCNP neutrons (0.1 MeV – 500 MeV)

Discussion - OTHER

Pulse Shape Discrimination (PSD)

N. D'Olympia et al. / Nuclear Instruments and Methods in Physics Research A 714 (2013) 121–127

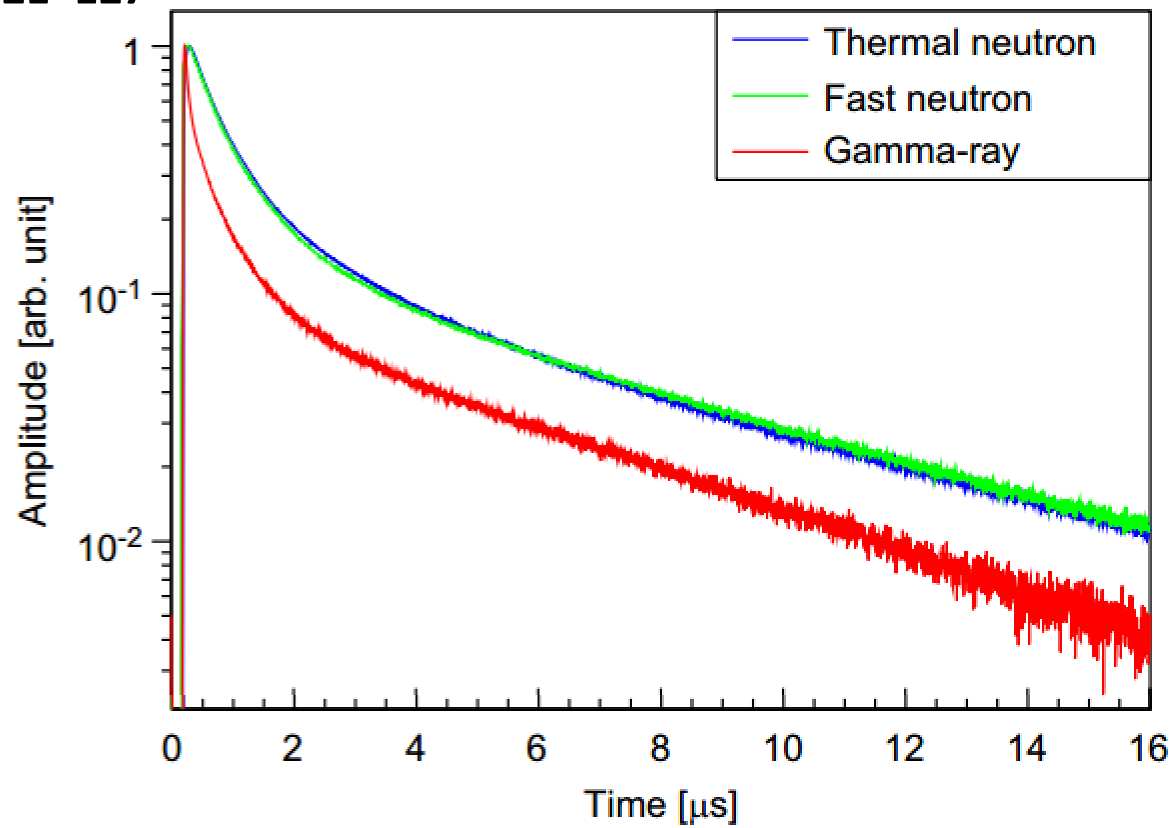


Fig. 5. Overlay of electron, proton, and α-triton super-pulses. Proton and α-triton pulses are very similar. [5]

Discussion - OTHER

Pulse Shape Discrimination (PSD)

N. D'Olympia et al. / Nuclear Instruments and Methods in Physics Research A 714 (2013) 121–127

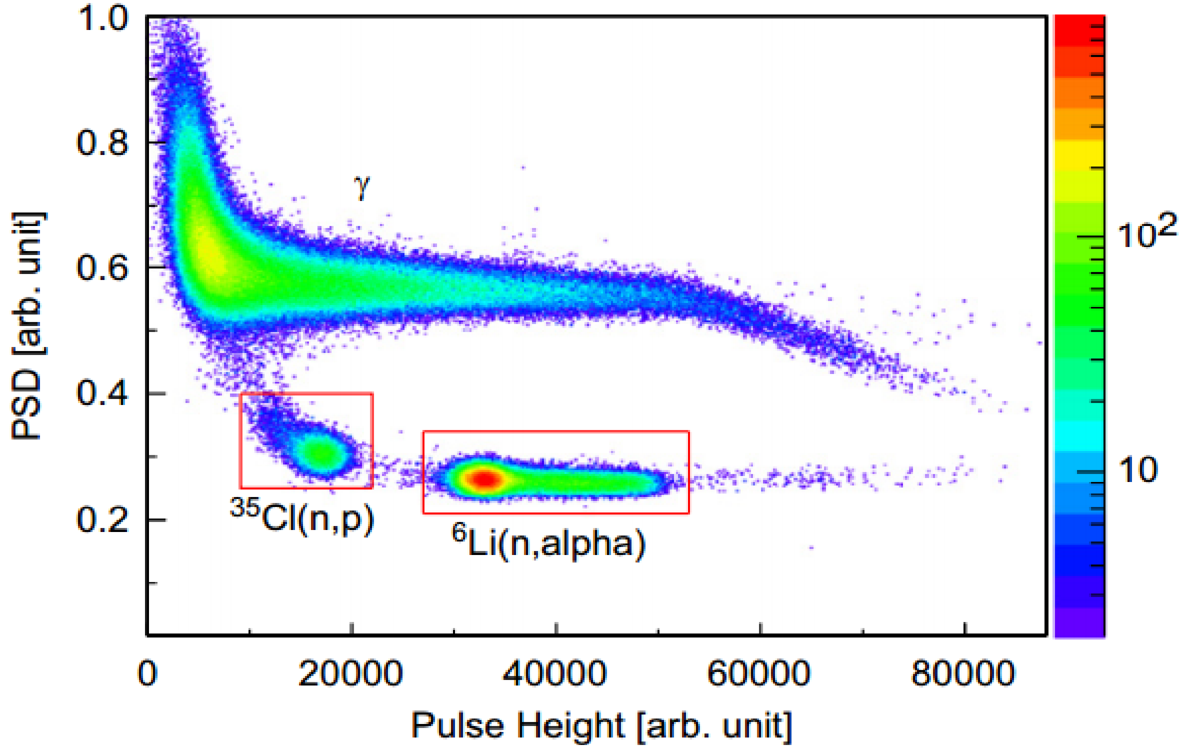
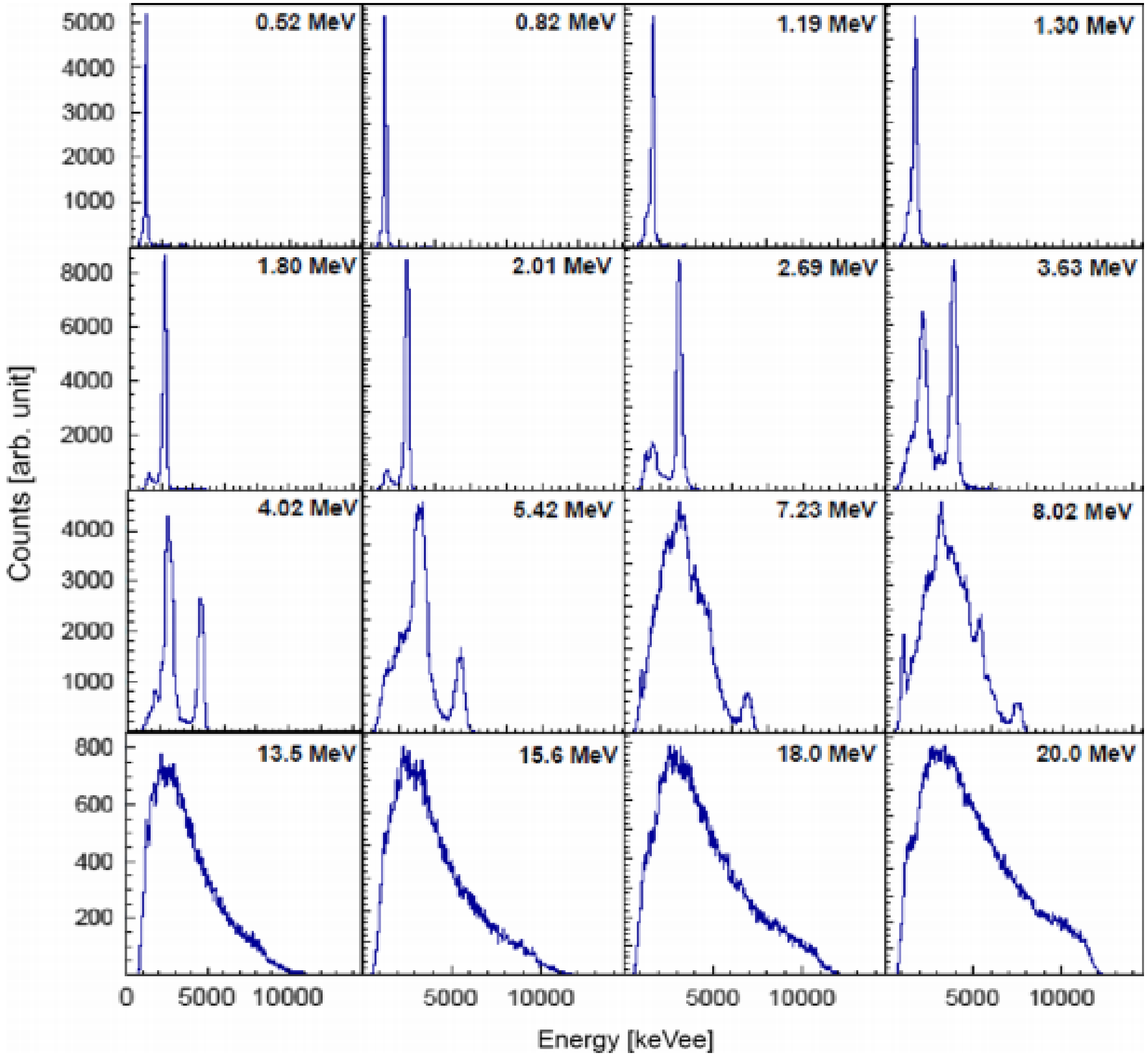


Fig. 3. PSD plot for 1.3 MeV fast neutron data. γ-ray, ^{35}Cl(n,p), and ^{6}Li(n, α) events indicated. [5]

Discussion - OTHER

Other Experiments

N. D'Olympia et al. / Nuclear Instruments and Methods in Physics Research A 763 (2014) 433–441



University of Kentucky Accelerator Laboratory [6]

Discussion -OTHER

Other Experiments

N. D'Olympia. “Development of a new fast neutron spectrometer using 6Li-depleted Cs2LiYCl6 scintillators”. PhD Thesis. University of Massachusetts Lowell (2014)

LANSCE Spallation Source

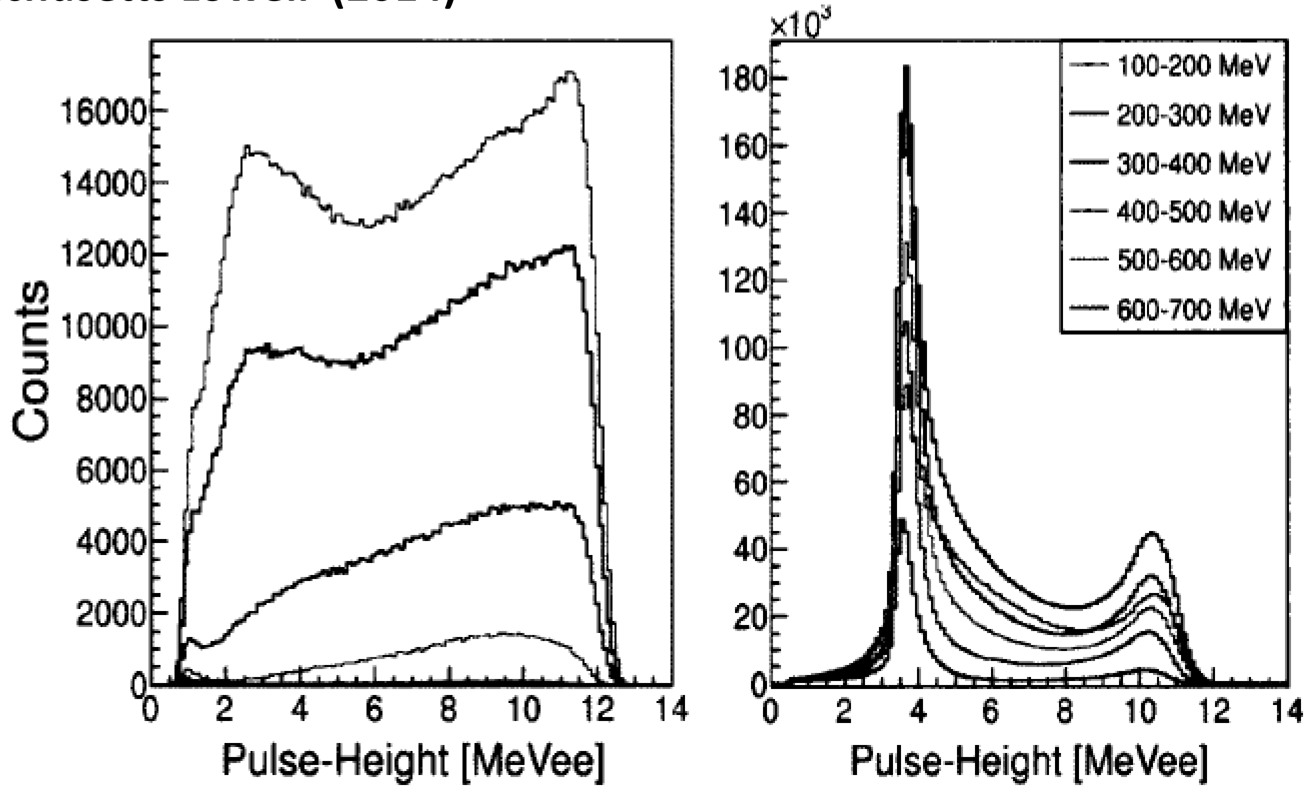


Figure 5.16: Left: Pulse-height spectra for 100-700 MeV neutrons within red PSD cut. Right: Spectra for neutrons within black PSD cut. Legend applies to both plots. [7]

Conclusion

- Used MCNP to investigate ^{7}Li enriched CLYC detectors
  - Secondary peaks begin around 2 MeV and become dominant above 8 MeV
  - High energy neutrons produce many protons and alphas with widely varying energy
- Experimental Results
  - Clear proton peak is linear with increasing neutron energy (below 8 MeV)
  - Experiment fit MCNP results closely

Future Work

- Data acquisition system including PSD for neutron gamma separation
- Experiments with high energy neutrons and mixed neutron fields
- Solid State Photomultiplier (SSPM)
- Unfolding to determine incident neutron energy

Thank You

References

[1] R. Machrafi, N. Khan, and A. Miller, "Response functions of Cs2LiYCl6: Ce scintillator to neutron and gamma radiation," *Radiat. Meas.*, vol. 70, pp. 5–10, Nov. 2014.

[2] R. Machrafi, A. L. Miller, and N. Khan, "New approach to neutron spectrometry with multi element scintillator," *Radiat. Meas.*, vol. 80, pp. 10–16, Sep. 2015.

[3] Jagdish K. Tuli et al., "Nuclear Data Sheets, National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY 11973-5000". http://www.nndc.bnl.gov

[4] ENDF/B-VII.1, 2014. Nuclear Energy Agency, Java-based Nuclear Data Information System, JANIS.

Thank You

References

[5] N. D'Olympia, P. Chowdhury, C. J. Lister, J. Glodo, R. Hawrami, K. Shah, and U. Shirwadkar, "Pulse-shape analysis of CLYC for thermal neutrons, fast neutrons, and gamma-rays," *Nucl. Instrum. Methods Phys. Res. Sect. Accel. Spectrometers Detect. Assoc. Equip.*, vol. 714, pp. 121–127, Jun. 2013.

[6] N. D′Olympia, P. Chowdhury, E. G. Jackson, and C. J. Lister, "Fast neutron response of 6Li-depleted CLYC detectors up to 20MeV," *Nucl. Instrum. Methods Phys. Res. Sect. Accel. Spectrometers Detect. Assoc. Equip.*, vol. 763, pp. 433–441, Nov. 2014.

[7] N. D′Olympia "Development of a new fast neutron spectrometer using 6Li-depleted Cs2LiYCl6 scintillators" PhD Thesis.University of Massachusetts Lowell, 2014