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.
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  – Radiation Detection System
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Introduction

Neutron Detection - CLYC

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

$^{35}\text{Cl}(n,p)$

Cs$_2$LiYCl$_6$:Ce Scintillator

Cross Section, b

Energy, MeV

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

\textbf{Cs}_2\text{LiYCl}_6:\text{Ce Scintillator}

\begin{align*}
\frac{1}{3}n + \frac{6}{3}\text{Li} & \rightarrow \frac{3}{1}\text{H} + \frac{4}{2}\text{He} \quad Q = 4.78 \text{ MeV} \\
\frac{1}{3}n + \frac{35}{17}\text{Cl} & \rightarrow \frac{35}{16}\text{S} + \frac{1}{1}\text{p} \quad Q = 0.615 \text{ MeV}
\end{align*}

Figure 2: CLYC spectra

\text{\textsuperscript{6}Li reaction (n,\alpha) dominates so 99\% \textsuperscript{7}Li enriched CLYC is used}
Methodology

MCNP Simulation

- MCNPX radiation transport code
- 99% $^7\text{Li}$ 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 $\text{Cs}_2\text{LiYCl}_6$:$\text{Ce}$ 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$_2$LiYCl$_6$:Ce scintillator
Methodology

Experimental Investigation

UOIT neutron generator

- **Mono energetic neutrons**
  - 2.5 MeV

Spectrum techniques rss-8 gamma button sources

![UOIT neutron source](image)

\[
\frac{2}{1}H + \frac{2}{1}H \rightarrow \frac{1}{0}n + \frac{3}{2}He
\]
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

\[
\frac{1}{1}p + \frac{7}{3}Li \rightarrow \frac{1}{0}n + \frac{7}{4}Be
\]

\[
\frac{2}{1}H + \frac{2}{1}H \rightarrow \frac{1}{0}n + \frac{3}{2}He
\]

Figure 6: McMaster LINAC
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 $^{22}\text{Na}$ button source

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

2.5 MeV neutrons

\[ \frac{1}{0}n + \frac{35}{17}Cl \rightarrow \frac{35}{16}S + \frac{1}{1}p \]

\[ Q = 0.615 \text{ MeV} \]

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

Figure 10: Excited state energy levels [3]

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

MCNP Analysis

$E_n = 2.67$ MeV

$E_n = 3.57$ MeV

$E_n = 4.0$ MeV

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

Counts per

Energy, MeV
Discussion

MCNP Comparison

Converted MeV 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

4.0 MeV

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

Protons + alphas

Figure 15: MCNP neutrons (0.1 MeV – 5 MeV)
Due to excited states of $^{35}\text{S}$ and $^{32}\text{P}$ from $^{35}\text{Cl} (n,p)$ and $(n,\alpha)$ reactions.

Figure 17: Excited state cross sections [4]
Discussion

MCNP high energy neutrons

Figure 18: MCNP neutrons (0.1 MeV – 500 MeV)
Discussion - OTHER

Pulse Shape Discrimination (PSD)


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)

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714 (2013) 121–127

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

Other Experiments


University of Kentucky Accelerator Laboratory [6]

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
References


References

