EPJ Web of Conferences 66, 11018 (2014)
DOI: 10.1051/epjconf/20146611018

Neutron and Gamma-ray Detection using a Cs_2LiYCl_6 Scintillator

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Abstract. A new scintillator, Cs_2LiYCl_6 (CLYC), has recently gained interest due to its dual capability to detect neutron and gamma radiation. In addition to its high resolution to detect gamma-rays, this sensor can serve in detecting both thermal and fast neutrons through ^{6}Li(n,α) and ^{35}Cl(n,p) reactions, respectively. For fast neutron detection, the current sensor technology has challenges and drawbacks, such as detection efficiency and energy dependence. In this regard, due to the presence of the ^{35}Cl isotope, CLYC can overcome those challenges. The response functions of this scintillator to neutron and gamma radiation has been obtained using Monte Carlo N-Particle eXtended code (MCNPX). The simulation results and the sensor's applicability to neutron spectrometry and dosimetry has been discussed and analyzed.

1 Introduction

Neutron spectrometry is a fundamental part of the dose calculation of individuals working in nuclear facilities due to its dependence on the incident neutron energy. Traditionally, thermal neutrons have been detected using ^{3}He, ^{6}Li, and ^{10}B based detectors which have a high neutron absorption cross section at thermal energies. Currently, there are two main methods used to detect fast neutrons. The first method uses the neutron scattering process on ^{1}H; and the second method slows down neutrons in a moderator medium and captures them at thermal energies. The drawback with the first method is that the neutron energy transferred to the proton highly depends on the scattered angle. As a result, a distribution of energies from the emitted protons is observed and complicated unfolding techniques are required to determine the incident neutron energy. While in the second method, the spectral information is lost after the neutron thermalization. Recently, there has been a newly developed sensor, Cs_2LiYCl_6:Ce, which has been tested mainly for thermal neutron detection based on the ^{6}Li(n,α)^{3}H reaction [1-5]. Another useful reaction that can be utilized for fast neutron detection is ^{35}Cl(n,p)^{35}S. In this reaction, the energy from the emitted proton can be observed as a distinct peak in the detector response function. The energy value at this peak is the sum of the incident neutron energy and the *Q*-value of the reaction. The CLYC scintillator therefore provides an alternative method to perform fast neutron spectroscopy. This paper presents the response functions of a CLYC scintillator to neutron and gamma radiation. Simulated detector response functions were obtained using Monte-Carlo N-Particle eXtended code (MCNPX).

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2 Methodology

Depending on the neutron energy and isotope the interaction occurs with, neutrons may undergo a few reactions in the CLYC crystal. At thermal energies, a neutron is detected through the capture reaction on ^{6}Li that has a cross section of 940 barns:

$$ {}_{0}^{1}n + {}_{3}^{6}Li \rightarrow {}_{1}^{3}H + {}_{2}^{4}He \tag{1} $$

The *Q*-value of this reaction is 4.78 MeV where the alpha particle takes 2.05 MeV and the triton takes 2.73 MeV. At high energies, the incident neutron interacts with the ^{35}Cl isotope through the following reaction:

$$ {}_{0}^{1}n + {}_{17}^{35}Cl \rightarrow {}_{16}^{35}S + {}_{1}^{1}p \tag{2} $$

The *Q*-value of this reaction is 0.615 MeV. The emitted proton has energy equal to the *Q*-value of this reaction plus the incident neutron energy; therefore the incident neutron energy can be deduced using this full energy peak.

2.1 Cs_2LiYCl_6 scintillator model

CLYC is a cylindrical inorganic crystal that has a density of 3.31 g/cm^3. It has three light decay times; 1, 50, or 1000 nanoseconds, a very high light output of 73,000 photons/neutron for thermal neutrons, 22,000 photons/MeV gamma-ray, and a maximum wavelength of emission of 370 nanometers. A 1 inch x 1 inch CLYC scintillator was modeled in MCNPX [6].

3 Results and discussion

3.1 Gamma radiation

The detector was irradiated with ^{137}Cs, ^{60}Co, and ^{22}Na at a distance of 10 cm from the detector. The pulse height spectrum, with an ideal resolution, is presented in Figure 1.

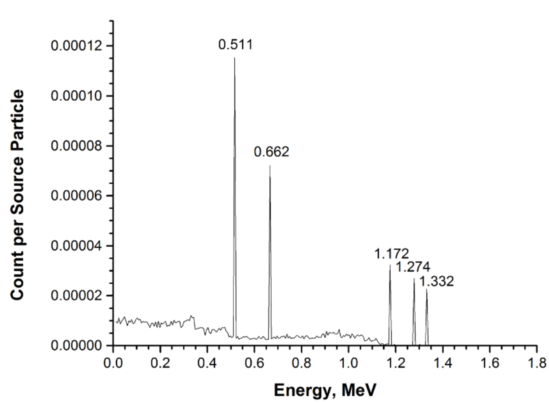

Figure 1. Detector response function to ^{137}Cs, ^{60}Co, and ^{22}Na.

The x-axis represents the scintillation light from the energy deposited by the electrons in the crystal. The prevalent gamma interactions are clearly seen with this scintillator i.e. the photoelectric effect and Compton scattering. The photoelectric peaks at 0.662 MeV corresponds to ^{137}Cs, 0.511 MeV and 1.274 to ^{22}Na, and 1.172 and 1.332 MeV to ^{60}Co, which are are clearly distinguished.

3.2 Neutron radiation

The detector was irradiated with different neutron energies from 0.1 MeV to 1.5 MeV. These energies were chosen based on their weight in the neutron fluence-to-dose conversion factor. Figure 2 shows the response functions to neutrons for 0.1, 0.5, 1, and 1.5 MeV. Due to the large gap of *Q*-value for both reactions on ^{6}Li and ^{35}Cl, the scintillator can tolerate detecting fairly high energy neutrons without any peak interfering for a wide range of energies. This means that this sensor can detect up to around 4 MeV neutrons without any overlapping of the peaks. This is very useful for fast neutron spectrometry. Particularly, for use in nuclear power plants, where the energy range of neutrons is from thermal to a few MeV.

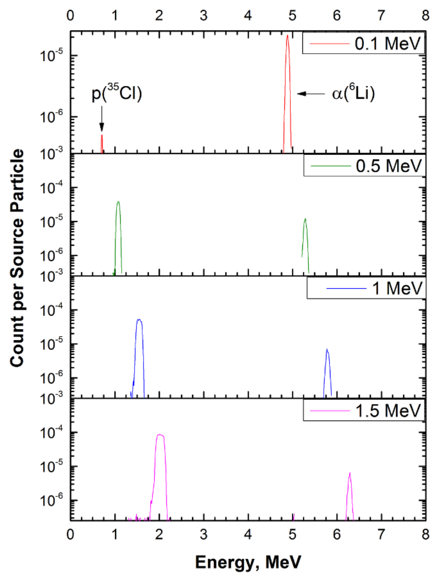

Figure 2. Detector response functions to different neutron energies

Both reactions with ^{6}Li and ^{35}Cl have distinct peaks on the spectra, corresponding to the *Q*-value of the reaction plus the incident neutron energy. Therefore, as the neutron energy increases, the peak of the emitted proton shifts proportionally. Even though, at some energies, the $^{6}Li(n,\alpha)$ reaction has a higher cross section, due to the greater abundance of ^{35}Cl in the crystal, the $^{35}Cl(n,p)$ reaction rate increases. In addition, due to the cross section and the isotopic abundance in the crystal, one can see that at 0.1 MeV, the number of events in the proton peak relative to the number of events in the alpha peak is negligible. However, this number increases with the incident neutron energy, while the events corresponding to alpha particles from the reaction with ^{6}Li decreases. There is no experimental data available for the $^{35}Cl(n,p)$ cross section at high energy neutrons to evaluate the sensitivity of the sensor to fast neutrons. However, a recent measurement carried out with a natural Li CLYC crystal did show a clear signature of protons on the pulse height spectra [7]. In our ongoing investigation with 95% enriched ^{6}Li, we have not observed any proton peak due to the dominant (n,α) reaction on the ^{6}Li isotope as opposed to (n,p) reaction on ^{35}Cl.

4 Conclusion

A Cs_2LiYCl_6 scintillator has been simulated for its potential use in neutron and gamma spectrometry. A Monte Carlo model was developed using MCNPX code and irradiated with different energies of neutrons and gamma-rays. Simulated response functions were investigated and the results showed that this scintillator has the capability to simultaneously perform neutron and gamma spectrometry in a wide range of energies. With a good resolution, the neutron/gamma energy spectra can be derived.

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