New approach to neutron spectrometry with multi element scintillator

R. Machrafi[*], A.L. Miller, N. Khan

Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, 2000 Simcoe North, Oshawa, Ontario, L1H7K4, Canada

HIGHLIGHTS

- Elpasolite scintillator CLYC.
- The scintillator mounted on a photomultiplier has been tested with different gamma and fast neutrons.
- The response functions of the detector have been measured.
- Monte Carlo simulations have been performed.
- The experimental and simulation data have been presented.

ARTICLE INFO

ABSTRACT

A recently developed scintillator has been investigated for possible use as a dual detector for neutron and gamma spectrometry. A 7Li-enriched version of the scintillator has been investigated. The $^{35}Cl(n,p)^{35}S$ nuclear reaction provides a possibility for fast neutron detection. The sensor has been mounted on a photomultiplier tube controlled with a miniature electronics board and irradiated in different gamma and neutron radiation fields. A series of experiments has been carried out with different gamma energies as well as well with mono-energetic neutrons from a KN Van de Graaff accelerator, and the pulse height spectra have been measured. To clarify different features observed on the response functions of the detector, a Monte Carlo model of the scintillator has been built using MCNP6 and emitted charged particles have been tracked. The simulation data along with the experiments are analyzed, compared and reported.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

In current technology, the detection of neutrons employs detectors with a high thermal neutron response such as Helium, Lithium and Boron surrounded by a thermalizing medium. Due to reasonable detection efficiency and good discrimination ability of gamma rays, this modest approach has been used for decades. However, it provides no information on the neutron energy and, therefore, it is fundamentally unable to identify neutron sources commonly encountered. Furthermore, at the position of the detector/source, the thermal neutron fluence is influenced by the surrounding materials. Consequently, the detection of thermal neutrons alone is unable to qualitatively evaluate the output of neutron sources. The second approach uses the neutron scattering process on hydrogen (plastic or liquid scintillators). In these detectors, the neutron energy transferred to the scattered proton highly depends on the scattered angle and consequently a continuous distribution of energies from the scattered protons is observed. Thus, to determine the incident neutron energy spectra, complicated unfolding techniques are required. In terms of detection efficiency, theses detectors have the advantage of being one of the least expensive. However, in addition to their lower light output for neutrons compared to gamma rays, they have no particular capability to distinguish neutron from gamma-ray signals. The limitations mentioned above demonstrate the importance of two key points in neutron spectrometry i.e. the physical proprieties of the neutron sensor and algorithms involved in unfolding the neutron spectra. With respect to the neutron sensor, limitations are

* Corresponding author.
E-mail address: rachid.machrafi@uoit.ca (R. Machrafi).

mainly related to the detection efficiency and the energy dependence. Both are associated with the basic physical properties of the neutron sensors (Alberts et al., 2001; Schutz et al., 2003; Barthe et al., 1998; Bartlett et al., 1999).

Recently, new sensors based on multi-elements have been developed to produce high detection efficiency scintillators. Among them, one can cite the Cs_2LiYCl_6: Ce (referred to as CLYC) family. These sensors have been tested mainly for thermal neutron detection based on the $^6Li(n,\alpha)^3H$ reaction (Combes et al., 1999; Bessiere et al., 2004; Bessiere et al., 2005; Glodo et al., 2008; Higgins et al., 2010; Glodo et al., 2011). However, beside the ^6Li isotope, the sensor also contains ^{35}Cl, with which a useful reaction can be utilized for fast neutron detection i.e. $^{35}Cl(n,p)^{35}S$. This reaction has been studied in one of our previous works with low energy neutrons, 2.5 MeV neutrons (Gledenov et al., 1999; Machrafi et al., 2014) and recently with mono-energetic neutrons (Smith et al., 2013; Smith et al., 2014; D'Olympia et al., 2013; D'Olympia et al., 2014). The cross section of this reaction, for energies higher than a few hundred keV, can play a significant role in fast neutron spectrometry since the energy of the emitted protons is observed as a distinct peak on the detector response function and its position varies linearly with the energy of the incident neutron. Although the sensor contains the ^6Li isotope with which neutrons interact through the $^6Li(n,\alpha)^3H$ reaction, the large difference in the deposited energy between the $^{35}Cl(n,p)^{35}S$ proton and $^6Li(n, \alpha)^3H$ alpha particles make the distinction between the two particle events easily achievable. In our previous paper, we have not seen any signature of protons emitted from the $^{35}Cl(n,p)^{35}S$ reaction when a 95%-^6Li-enriched CLYC has been exposed to fast neutrons due to the dominance of the $^6Li(n,\alpha)^3H$ reaction (Machrafi et al., 2014). A new version of the CLYC (referred to as ^7Li-enriched CLYC (99% of ^7Li)) has been used in the current study. The response function of this sensor to different neutron and gamma energies has been investigated.

The present paper focuses on results of a series of experiments to investigate the capability of CLYC scintillators to detect fast neutrons. The neutron pulse height spectra have been measured and analyzed. In addition, the detector has been modeled using the MCNP6 Monte Carlo code to clarify the origin of other peaks observed in the experimental response functions.

1.1. Methodology description and experimental setup

The elpasolite scintillator Cs_2LiYCl_6: Ce(CLYC) is an inorganic crystal recently developed by Radiation Monitoring Device RMD (Radiation Monitoring Device, 2014). The crystal is a cylinder with a 2.54 cm diameter, 2.54 cm length and a density of 3.31 g/cm^3. Depending on the dopant, the crystal has different light decay times (Bessiere et al., 2005). The first version of the scintillator with 95% enriched ^6Li was investigated in our previous paper (Machrafi et al., 2014). The current version contains 99% ^7Li and all other elements are in their natural abundances. The crystal has been coupled with a one inch photomultiplier R3998-02 from Hamamatsu and connected to a compact miniature data acquisition system that consists of a multichannel analyzer (MCA) developed by Bridgeport (Bridgeport Instruments, 2009). A simplified schematic of the experimental setup is shown in Fig. 1.

Measurements were carried out at the Applied Radiation Laboratory-Neutron Facility at the University Of Ontario Institute Of Technology as well as at the KN Van De Graaff accelerator at McMaster University, Canada. For experiments with gamma radiation, the detector has been irradiated with standard gamma sources that include ^{137}Cs, ^{60}Co and ^{22}Na for a range of energies up to 1.332 MeV. The results have been reported in our previous paper (Machrafi et al., 2014)
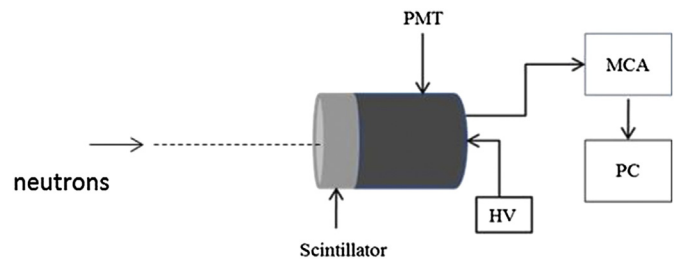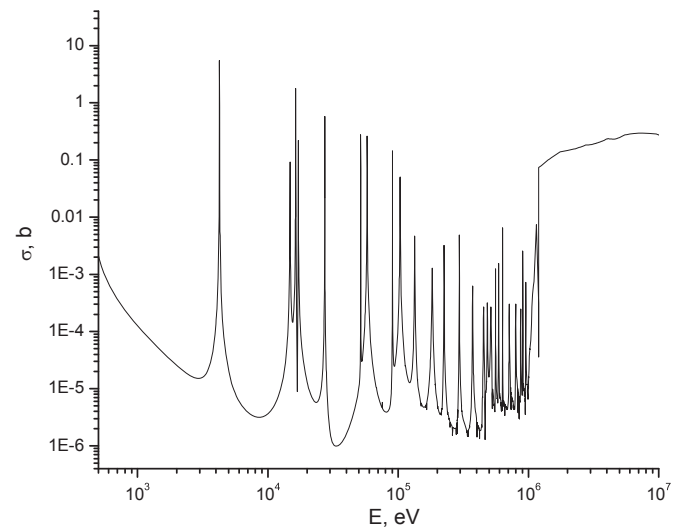

Fig. 1. Schematic of the experimental setup.

Fig. 2. ^{35}Cl (n,p) reaction cross section (ENDF/B-VII.1, 2014).

For neutrons, a series of experiments with mono-energetic neutrons from 0.6 to 4 MeV have been carried out. When neutrons interact with the scintillator, they undergo two main different reactions, one with ^6Li through the (n, α) reaction which is mainly with low energy neutrons (due to its high cross section). This reaction releases an energy of 4.78 MeV and a peak on the pulse height spectra appears at a fixed position of around 3.24 MeV
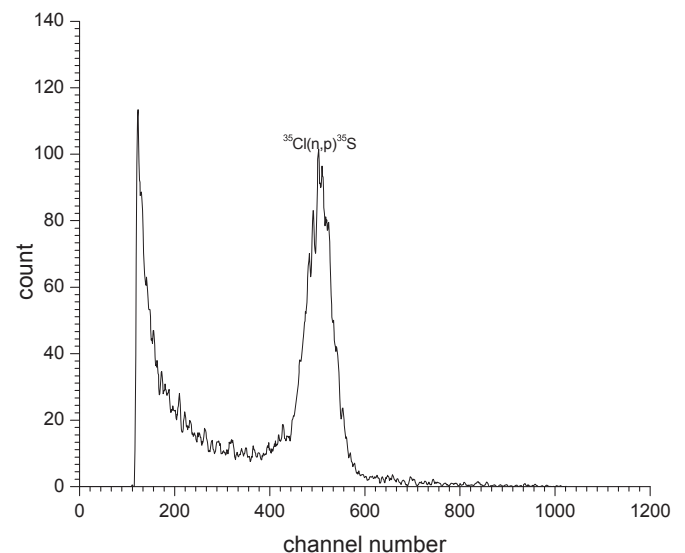

Fig. 3. Pulse shape spectra with intermediate neutrons (around 0.5 keV).