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Low-energy neutron flux measurement using a resonance absorption filter surrounding a lithium glass scintillator

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Abstract

The resonance absorption filter technique has been used to determine the thermal/epithermal neutron flux. The main idea in this technique is to use an element with a high and essentially singular resonance in the neutron absorption cross section as a filter surrounding a miniature-type lithium glass scintillator. The count with and without the filter surrounding the detector gives the number of resonance-energy neutrons. Some preliminary results and a comparison with the MCNP code are shown.

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Keywords: Resonance absorption; Filter; Glass scintillators; MCNP code

1. Introduction

The determination of neutron flux in the range of thermal and epithermal energies is of high importance due to the large number of applications in medical investigations, especially epithermal neutrons with energies from 0.5 eV to 10 keV, which have been recently used in cancer therapy, and proved to be more penetrating and less destructive (Allen and Beynon, 1995).

In this paper the use of a resonance absorption filter is studied to measure the low-energy neutron flux. The filter is an element with a high and singular resonance in neutron absorption cross section, which is located surrounding the cylindrical detector. Neutrons at the resonance energy are preferentially absorbed and, by taking measurements with and without the filter in place, a measure of the flux at the resonance energy can be obtained (Hamidi and Scott, 2002).

The detector is a miniature lithium glass scintillator of which its small size (a cylinder with 5 mm diameter by 24 mm high) provides an approximately complete mapping of the space.

The neutron source used in this research is an Am–Be type, which produces 10^7 neutrons per second with energies ranging from thermal (0.025 eV) up to 11 MeV.

The resonance filter is CsI with the main resonance at 5.6 eV, 3 mm thickness, for which the corresponding neutron absorption and elastic scattering cross sections are 2.65×10^3 and 1.7×10^2 b. To remove thermal neutrons, a one-millimetre cadmium filter was placed over the main filter.

The whole experiment was modelled using Monte Carlo neutron transport code, MCNP (Briesmeister et al., 2000). The overall agreement between experimental and theoretical results was excellent.

2. Lithium glass scintillator

Scintillators are solid, liquid or gaseous materials which give visible (or near-visible) light when subjected to an ionising radiation. Li-glass scintillators are silicon-based glasses doped with a few weight-percent lithium. In the case of neutron detection, the ^{6}Li content is enriched, whilst

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those glass scintillators enriched in ^{7}Li are insensitive to neutrons, but suitable for gamma ray detection (Weber, 2002). The activator element in Li-glass scintillator is cerium in the form of Ce_2O_3. The lithium glass of the detector used in this study was a GS20 cylinder (5 mm diameter by 24 mm high), 95% enriched in ^{6}Li (Applied Scintillation Technologies Ltd., 1999). The main reaction for the neutron detection in this scintillator is

$$n + {}^{6}_{3}\mathrm{Li} \rightarrow {}^{3}_{1}\mathrm{H} + {}^{4}_{2}\alpha + 4.78\,\mathrm{MeV},$$

where the alpha and triton particles lose their energies within the scintillator volume. The surface of the scintillator was painted (with TiO_2 paint) using a special technique (case 1 of Fig. 7 in (Ghal-Eh and Koohi-Fayegh, 2006)) to achieve the best resolution and at the same time optimum light output. A very long (11 cm) Perspex light guide was used in order to transmit light photons to a 0.5-inch photomultiplier (Ghal-Eh et al., 2004). Fig. 1 shows the Li-glass scintillator and its main parts.

Neutrons (corresponding to Gaussian part of the curve), as shown in pulse-height spectrum (Fig. 2), are very well separated from the rest (exponential part of the curve). The probable sources of the exponential part are gammas (which always accompany the neutron source) and the electronic noise. The gammas are attributable to the neutron reaction with ^{6}Li, giving rise to an excited state of ^{7}Li*, and consequently a decay to ground state.

The peak of the Gaussian is located at 4.78 MeV, which is the energy released from ^{6}Li(n, α)^{3}H reaction. Gamma rays are converted to electrons due to the interaction with aluminium housing of the detector and also via reaction with scintillator atoms. Although the amount of energy released by the electrons is much less than that by the neutrons, there is an overlap in the pulse-height curve, which is a source of discrepancy between experimental and theoretical results to be discussed in Section 5.

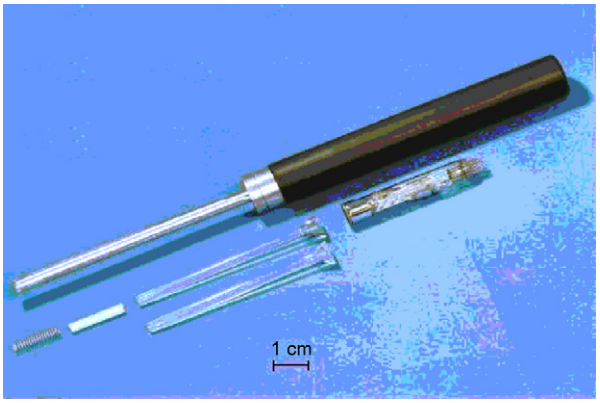

Fig. 1. The Li-glass scintillator detector with two different light guides, a 24 mm long Li-glass scintillator covered with reflecting paint and the 12.5 mm PM tube.

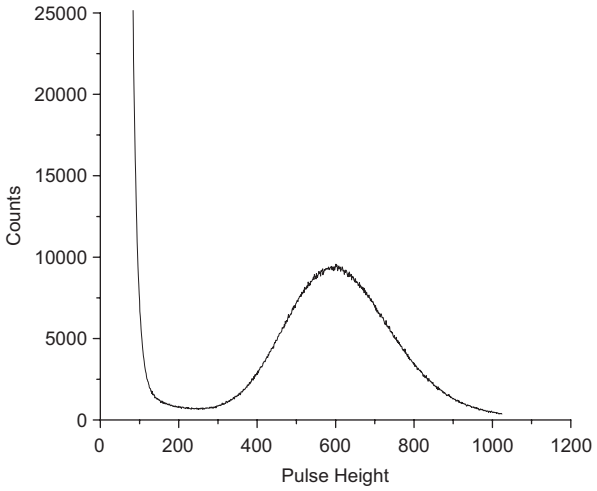

Fig. 2. A typical pulse-height spectrum of a lithium glass scintillator.

3. Resonance absorption filter technique

The neutron spectroscopy is more difficult than charged-particle and gamma-ray spectroscopies for which there are at least three reasons:

(1) neutrons are neutral particles and so are detected via indirect nuclear reactions. The cross sections of these reactions are highly dependent on the neutron energy and the reacting nucleus;
(2) the neutron energy is normally distributed over a wide range of energies from thermal to tens of mega electron volts;
(3) neutrons are always accompanied with gamma rays, which interfere with the neutron detection, so must be separated from the neutron spectrum.

Each of the neutron spectroscopy techniques is used in a special range of energies and has its own precision limits. In other words, to be able to choose a particular spectroscopy technique, one should know the range of neutron energies and also the precision to which one may be interested.

Among possible techniques for low-energy neutrons, the resonance activation method using (n, γ) reaction has been proved to be efficient, but the main problem is to find an element with a large resonance within the neutron energy range of interest. This element, in the form of a foil, will efficiently absorb the resonance neutrons. The produced radioactivity is a measure of original neutron flux. The high neutron flux and a large neutron absorption cross section are two limitations which cause this technique to be applied to only a few elements at low neutron flux.

The basis governing the resonance absorption filter technique is different. The element with a resonance in the neutron absorption cross section acts as a filter. The number of neutrons absorbed within the filter depends directly on the thickness of the filter. When the thickness is increased, the contribution of the adjacent resonances is also increased so more neutrons are absorbed by the filter.

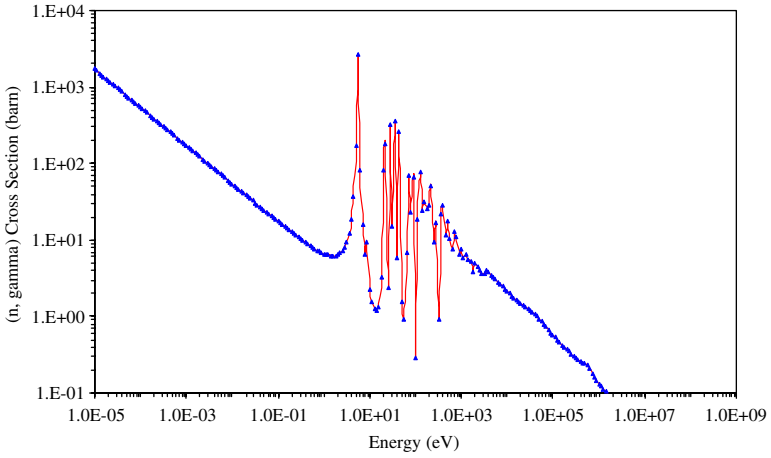

Fig. 3. (n,γ) cross section of CsI resonance filter with the main resonance at 5.6 eV (JEF PC, 1994).

As shown in Fig. 3, the main resonance (5.6 eV for CsI) is always accompanied by some smaller adjacent resonances, for which it is recommended to use thin filters, normally at the same order of mean free path of the resonance neutron inside the filter (Hamidi, 2000). The neutron cross section increases as the neutron energy decreases and becomes comparable with resonance cross section for thermal neutrons. So thermal neutrons are highly absorbed by the filter. To get rid of this problem, a one-millimetre cadmium is used to remove neutrons with energies below 0.5 eV and at the same time improve the uncertainty of the results.

So three measurements are carried out:

(1) neutron flux measurement with detector only;
(2) neutron flux measurement with Cd-filter and detector;
(3) neutron flux measurement with Cd-filter, resonance-filter (e.g. CsI) and detector.

The difference between cases (1) and (2) gives the thermal neutrons, whilst the difference between cases (2) and (3) gives the resonance (5.6 eV) neutrons. The ratio of the resonance to thermal neutrons may be considered as a measure of thermalisation of the neutron flux.

Measurements with different filters of different resonance energies will determine the neutron flux in terms of the corresponding energies.

4. Experiment and simulation

As discussed earlier a miniature lithium-glass scintillator was used as a detector in this study. Three different experiments were carried out: (1) detector only, (2) detector plus cadmium filter and (3) detector plus cadmium filter plus resonance filter.

To derive the number of neutrons coming from Am–Be neutron source, a Gaussian (corresponding to neutrons) and two exponential curves (corresponding to gammas and electronic noise) were fitted to pulse-height spectrum of the detector (Fig. 2). By statistical subtraction of the exponentials from the rest of the pulse-height spectrum, the Gaussian part is easily derived (Fig. 4). The area of the Gaussian gives the total number of the neutrons.

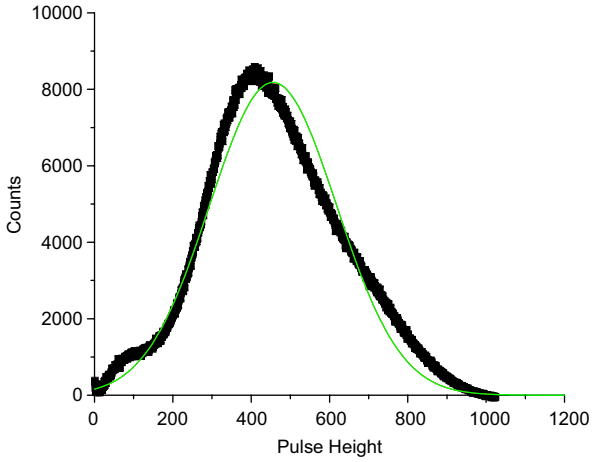

Fig. 4. The Gaussian curve corresponding to neutrons detected by Li-glass scintillator.

In measurements with cadmium (or resonance) filter, the contribution of the gamma rays in pulse-height spectrum is increased. There are two main reasons for this: (1) the number of neutrons reaching the detector is effectively decreased due to the absorption by the filter and (2) as neutrons are absorbed by the filter, a large number of gamma rays are produced through the (n,γ) reaction.

To check the experimental results, it was decided to compare them with Monte Carlo simulation (using MCNP code); this was due to the lack of such experimental results in the literature.

Table 1 shows the experimental and MCNP results. To have a better comparison, all values (both experiments and simulations) were normalized to the total count rate. The data given in Table 1 are also illustrated in Fig. 5 for a better comparison.

As it can be seen in cases (3) and (4), the detector-with-filter cases, some disagreements are observed.

Table 1
Experimental vs. MCNP results for five different cases shown in Fig. 5

		Counts (normalized to bare detector count (case 1))	
		MCNP (error)	Experiment (error)
Case (1)	Bare detector	$1 \pm 7.02(-2)$[a]	$1 \pm 6.25(-4)$
Case (2)	Thermal neutrons [case (1) – case (3)]	$0.917 \pm 7.08(-2)$	$0.809 \pm 7.5(-4)$
Case (3)	Detector + Cd filter	$0.083 \pm 8.62(-3)$	$0.234 \pm 4.14(-4)$
Case (4)	Detector + Cd filter + resonance filter	$0.0545 \pm 5(-3)$	$0.245 \pm 4.11(-4)$
Case (5)	Resonance neutrons [case (4) – case (3)]	$0.0283 \pm 9.97(-3)$	$0.0201 \pm 5.76(-4)$

[a] $1 \pm 7.02(-2) = 1 \pm 7.02 \times 10^{-2}$.

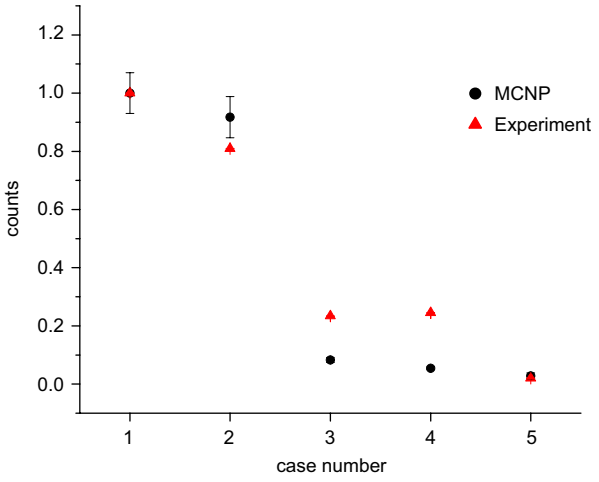

Fig. 5. Experimental vs. MCNP results for five different cases.

The reason is that a large number of gammas is detected by the scintillator, which causes the experimental result to be higher than the corresponding computational value.

The case (5), which gives the number of resonance neutrons, represents a very good agreement. This is due to the removal of the gammas after subtraction of the cases (3) and (4).

5. Conclusions and suggestions for the future works

The resonance absorption filter technique is a suitable choice for determining neutron flux in therapeutic investigations. Because of the high slowing down power of the water, the neutron flux changes drastically as the point of measurement changes. This method (in addition with a miniature type detector) makes the flux measurements in very close neighbouring points within the phantom possible.

The main source of error in this technique is the relatively large number of gamma rays detected in the glass scintillator. To reduce this error (and at the same time to improve the agreement between experimental and Monte Carlo simulation), it is suggested to: (1) improve the fitting method before subtracting areas described in Section 3 and (2) remove the gamma rays accompanying the neutrons as much as possible. A potential choice is to use two different glass scintillators, one enriched in ^{6}Li (very sensitive to neutrons) and the other depleted from ^{6}Li and enriched in ^{7}Li (insensitive to neutrons but still sensitive to gamma rays) (Taniguchi et al., 2001). The subtraction of the count rates of these scintillators determines the contribution of the gamma rays.

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References

Allen, A.D., Beynon, T.D., 1995. A design study for an accelerator-based epithermal neutron beam for BNCT. Phys. Med. Biol. 40, 807–821.
Applied Scintillation Technologies Ltd., 1999. Lithium glass scintillators for neutron detection. Data Sheet 6.
Briesmeister, J.F., et al., 2000. Present and future capabilities of MCNP. Appl. Radiat. Isot. 53, 857–861.
Ghal-Eh, N., Koohi-Fayegh, R., 2006. Light collection behaviour of scintillators with different surface coverings. Rad. Meas. 41, 289–294.
Ghal-Eh, N., Scott, M.C., Koohi-Fayegh, R., Rahimi, M.F., 2004. A photon transport model code for use in scintillation detectors. Nucl. Instrum. Meth. A 516, 116–121.
Hamidi, S., 2000. The use of neutron resonance filter techniques for verifying BNCT moderator calculations. Ph.D. Thesis, School of Physics and Astronomy, The University of Birmingham, UK.
Hamidi, S., Scott, M.C., 2002. BNCT neutron beam characterization using a resonance absorption filter method. Nucl. Instrum. Meth. A 476, 99–105.
JEF PC, 1994. A program for displaying data from the Joint Evaluated File. OECD/NEA Data bank, 12, Bld des Iles, 92130 Issy-Les-Moulineaux, France.
Taniguchi, S., Takada, M., Nakamura, T., 2001. Development of multi-moderator neutron spectrometer using a pair of ^{6}Li and ^{7}Li glass scintillators. Nucl. Instrum. Meth. A 460, 368–373.
Weber, M.J., 2002. Inorganic scintillators: today and tomorrow. J. Lumin. 100, 33–45.