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Absolute neutron fluence measurements between 0.5 and 3 MeV and their intercomparisons

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Abstract

Primary standards of monoenergetic neutron fluences for 0.565, 1.5 and 2.5 MeV neutrons produced by the $^7Li(p,n)^7Be$ reaction have been developed for the calibration of neutron dosimeters and spectrometers. The fluences for 0.565 MeV neutrons were measured using both H_2 and CH_4 proton recoil proportional counters with the measured spectra fitted to the modified SPEC-4 Monte Carlo simulations for the subtraction of gamma and recoil carbons. The fluences for 1.5 and 2.5 MeV neutrons were determined with vacuum-type proton recoil telescopes. Various uncertainties for each detector are analyzed and its overall uncertainty is 3.1% for gas counter and less than 3% for the telescope. These neutron fluence standards have been intercompared with those of the National Physical Laboratory of the United Kingdom by the use of two transfer instruments: a long counter and a ^3He detector. The comparison results will be presented and discussed. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Accurate monoenergetic neutron fluences are required for the calibration of neutron dosimeters and spectrometers. Various types of proton recoil telescopes (PRTs) have been employed for the absolute determinations of monoenergetic neutron fluences in the energy range of 1–30 MeV [1–3]. In order to eliminate the high backgrounds due to unwanted (n,p) and (n,α) reactions, three and even four stages of PRTs have been used for the neutrons with energies above 6 MeV [1,2].

Three significant results are presented in this paper. Firstly, an accuracy of better than 3% in the neutron fluence measurements with energies below 3 MeV can be achieved by using a single-stage vacuum-type proton recoil telescope. Secondly, the energy responses of various neutron detectors with energy range in 0.5–3 MeV can be deduced with the most easily fabricating Li-target and

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a mathematical subtraction process. And thirdly, the detection sensitivities of two transfer instruments have been measured and compared at the institute of nuclear energy research (INER) and the National Physical Laboratory (NPL) of the United Kingdom to demonstrate quality assurance in these primary measurements.

2. Neutron fluence measurements

2.1. Proton recoil telescope technique

For these neutron fluence measurements, either PRT or proportional counter was set up at 0° and a neutron monitor at 90° with respect to the direction of the proton beams. Neutron sources with energies from 0.5 to 3 MeV are produced from the ^{7}Li(p,n)^{7}Be reaction, in which the proton beams are provided by the 7 MV Van der Graaff accelerator at INER.

Due to the low backgrounds from the (n,p) and (n,α) reactions in the silicon surface barrier detector (SSD) for neutrons with energies below 3 MeV, single-stage vacuum-type proton recoil telescopes were used for the absolute neutron fluence measurements for neutrons with energies between 1 and 3 MeV. The configuration of the telescope is illustrated in Fig. 1, which is an improved version of that in Ref. [3], with several substantial improvements in its design and construction made in this work. The cylindrical vacuum chamber of the telescope is made of SS304, 110 mm long and 105 mm in diameter. To reduce neutron attenuation and scattering, the front window of the chamber is $\sim$ 0.2 mm thick and its side wall is $\sim$ 0.5 mm thick. A recoil proton absorber of SS304 disk ($\sim$ 0.2 mm thick) can be rotated to be located between the radiator and the SSD to take the backgrounds. To reduce the uncertainty of the detector area, a Cu collimator of 16.65 $\pm$ 0.05 mm diameter was manufactured, in which a low scattering surface ($\sim$ 0.6 mm thick) of proton collimator was designed. Typical vacuum of the telescope is 1×10^{-5} Torr.

Radiators with various thickness were made at this institute by vacuum evaporation on Ta-backing ($\sim$ 0.25 mm thick). Their thickness was measured by the weight of Ta-backing with

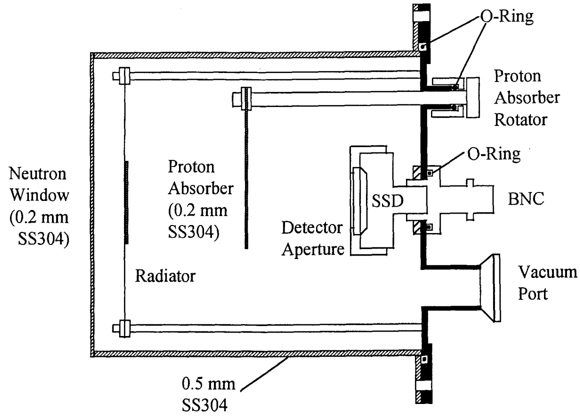

Fig. 1. Configuration of the vacuum-type proton recoil telescope.

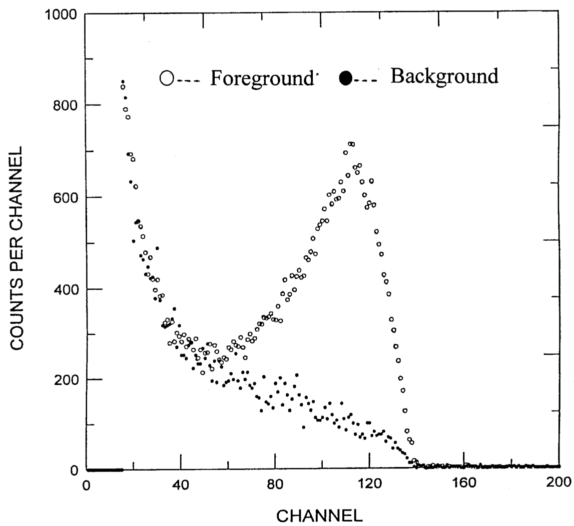

Fig. 2. Pulse-height distribution of the PRT with 2.23 mg/cm^2 radiator for 2.5 MeV neutrons.

a microgram balance before and after the evaporation of the tristearin($C_{57}H_{110}O_6$) divided by its area. Fig. 2 shows the pulse-height distribution for the 2.5 MeV neutrons from the telescope with the radiator of 2230 μg/cm^2.

The dominant neutrons with energies between 0.6 and 3 MeV produced from the ^{7}Li(p,n)^{7}Be are inherently associated with $\sim$ 10% of lower energy neutrons [4], in which its energy is $\sim$ 0.5 MeV below the high-energy neutrons. However, by the following calculations, the neutron fluences for the dominant high-energy neutrons can be deduced. If ϕ_ℓ and ϕ_h are the neutron fluence rates, ε_ℓ and ε_h are the detection sensitivities for the lower and high-energy neutrons, Ω is the solid angle subtended by the radiator and T_0 is the total time duration for the measurements, then the total counts of recoil protons in the telescope, C_p, can be expressed as

$$C_p = (\varepsilon_\ell \phi_\ell + \varepsilon_h \phi_h)\Omega T_0 = \varepsilon_h \phi_h \Omega T_0 \left(1 + \frac{\varepsilon_\ell \phi_\ell}{\varepsilon_h \phi_h}\right).$$

Thus, the neutron fluences for high-energy neutrons can be expressed as

$$\phi_h T_0 = \frac{C_p}{\varepsilon_h \Omega (1 + \varepsilon_\ell \phi_\ell / \varepsilon_h \phi_h)}, \quad (1)$$

which can be calculated quite easily with the neutron intensities for lower and high-energy neutron [4]. The detection sensitivities of the telescopes are calculated by the numerical integration using the same expression as that in Ref. [3], in which the distance for the SSD to radiator and the radiator to neutron sources is 43.3 ± 0.4 and 217.2 ± 0.4 mm, respectively. Various uncertainties for these telescope measurements are estimated in Table 1.

Table 1
Uncertainties in the proton recoil telescope fluence measurements for 1.5 and 2.5 MeV neutrons

Origin	Uncertainty (%)	
	1.5 MeV	2.5 MeV
Statistics (1σ)	0.6	0.7
Background subtraction	1.1	1.0
n–p scattering cross section	0.5	0.5
Radiator thickness	0.3	0.2
Internal telescope geometry	1.3	1.3
Telescope to target distance	0.4	0.4
Aperture scattering	0.6	0.6
Multiple scattering in radiator	1.1	0.9
Window attenuation	0.3	0.3
Subtraction of lower-energy neutrons	1.6	1.6
Overall	2.8	2.7

2.2. Proton recoil proportional counter technique

Both an H_2 proton recoil proportional counter and a CH_4 proportional counter were employed for neutrons with energies below 1 MeV. The cylindrical counters were obtained commercially and were sealed tubes. The active length of the two counters is 17.77 cm and the effective dia. is 36.3 mm. The H_2 counter was filled with 960 Torr of H_2 gas stabilized by 48 Torr of CH_4. The CH_4 counter was filled with 1376 Torr of CH_4.

In order to subtract the backgrounds from gamma and recoil carbons, a modified SPEC-4 Monte Carlo simulation code [5] has been employed to calculate the pulse-height distribution for each counter. Figs. 3 and 4 show the simulation results fitted to the experimental spectra.

3. Neutron fluence intercomparisons

Two transfer instruments were used for the neutron fluence intercomparisons, in which the neutron fluence measurements and the calibration of the two transfer instruments at NPL were described in Ref. [6]. In order to reduce the backgrounds from the scattered neutrons, a

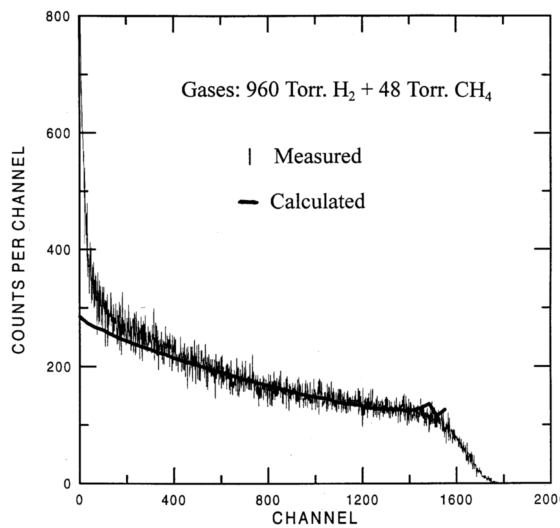

Fig. 3. Measured and calculated pulse-height distribution for 0.565 MeV neutrons on 1.5″ dia. cylindrical H_2 counter.

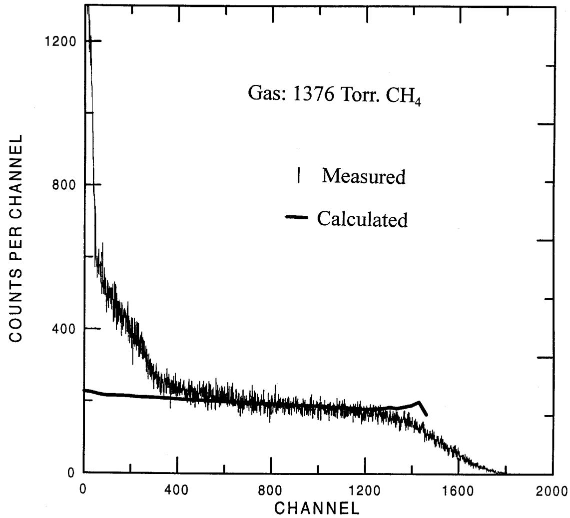

Fig. 4. Measured and calculated pulse-height distribution for 0.565 MeV neutrons on 1.5″ dia. cylindrical CH_4 counter.

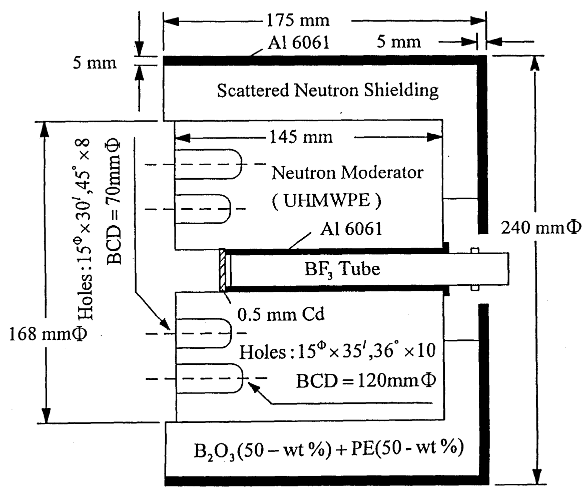

Fig. 5. Configuration of scattered-neutron shielded transfer long counter.

scattered-neutron shielded long counter as shown in Fig. 5 has been designed and fabricated at this institute.

Another transfer instrument is a commercial ^3He detector, in which its effective length, effective diameter and counter pressure is 20.3 cm, 4.75 cm and 3040 Torr, respectively. Moreover, the detector was shielded with 0.5 mm Cd to reduce signals from thermal neutrons.

4. Results and discussions

Table 1 shows various uncertainties associated with the vacuum-type telescope measurements, indicating that an accuracy of $\leqslant 2.8\%$ can be obtained for both the 1.5 and 2.5 MeV neutrons, in which the major uncertainty comes from the subtraction of the recoil protons from the lower-energy neutrons. The overall uncertainty of the neutron fluence for 0.565 MeV neutrons is 3.1% with the H_2 proton recoil proportional counter as shown in Table 2.

Table 3 shows the results of the comparisons for the transfer long counter at 160 cm from the target measured at two laboratories. Although the correction for scattered neutrons is higher at this institute

Table 2
Uncertainties in the proton recoil proportional counter fluence measurements for 0.565 MeV neutrons

Origin	Uncertainty (%)
Statistics (1σ)	0.4
Spectrum fitting and background subtraction	2.0
Active volume	1.1
Pressure	1.1
Effective center to target distance	1.1
Scatttered neutron subtraction	0.3
Dead-time correction	0.2
n–p scattering cross section	0.5
Air attenuation	0.3
Window attenuation	1.2
Overall	3.1

Table 3
Results of the comparisons for the transfer long counter at 160 cm from target

Neutron energy (MeV)	Laboratory	Correction for scattered neutrons (%)	Sensitivity (counts/(n/sr)) $\times 10^{-5}$
0.565	INER	6.1	1.94
	NPL	4.0	1.99
1.5	INER	8.0	2.05
	NPL	6.1	2.08
2.5	INER	11.4	1.88
	NPL	5.2	1.86

Table 4
Results of the comparisons for the ^{3}He detector at 100 cm from the target for the 0.565 MeV neutrons

Laboratory	Correction for scattered neutrons (%)	Detection sensitivity (counts/(n/sr)) $\times 10^{-6}$
INER	3.1	2.26
NPL	3.0	2.15

than that at NPL, their measured detection sensitivities are in very good agreements, which demonstrates the good quality in the primary measurements with telescopes at this institute. By adjusting the counter pressure to obtain an optimum fitting between the measured and the calculated spectrum, a correct counter pressure has been deduced. Table 4 shows the results of the comparisons for the ^{3}He detector at 100 cm from the target, which shows they are in reasonably good agreement.

5. Conclusions

Two important conclusions can be drawn from this work. Firstly, by a simple mathematical expression, the responses of various neutron detectors to the monoenergetic neutrons can be deduced with the dominant high-energy neutrons produced from the ^{7}Li(p, n)^{7}Be reaction. Thus, the rather easily contaminated ^{3}H-target can be avoided for the neutrons with energies between 0.5 and 3 MeV at a multiple-purpose accelerator laboratory. And secondly, an accuracy of better than 3% in the absolute neutron fluence measurements with energies from 1 to 3 MeV has been achieved with the vacuum-type proton recoil telescope, in which their quality assurance has been demonstrated by the good agreements in the intercomparison results with the NPL.

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