Measurements of neutron spectra from iron and boron-in-polyethylene bombarded with 14 MeV neutrons

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Abstract The leakage spectra of 14 MeV neutrons from spheres of iron and boron-in-polyethylene with three different mass ratios of boron carbide to polyethylene were measured over the energy range of 20 keV to 16 MeV by using proton recoil method. The integral leakages and removal cross sections at different lower cut-off energy were given.
Keywords Iron, Boron-in-polyethylene, D-T neutron, Leakage spectrum

1 Introduction

Iron and boron-in-polyethylene are widely used in the nuclear engineering and shielding, and the fusion-fission reactor blanket. An accurate description of the transported neutron spectrum from a 14 MeV source through those materials is required. Early in the 1970s C. Wong *et al*[1] had measured the neutron emission spectra from spheres of various materials with a 14 MeV source by the time-of-flight method in the Livermore pulse sphere program. But the data in the energy range of 1~2 MeV are absent. In the present work the leakage spectra of 14 MeV neutrons from spherical samples of iron and boron-in-polyethylene with different mass fractions of boron carbide were measured for evaluation of group neutron cross sections of nuclides and test of neutron transport calculations. The energy range of measured neutron spectrum is from 20 keV to 14 MeV. The removal cross sections per unit mass are more useful for design of radioprotection and shielding. Therefore, the removal cross sections of the materials at different lower cut-off energy are also given here.

2 Experimental

The samples consist of a set of spherical shells with a inner central hollow of 6 cm in diameter. The external diameters of four shells are orderly 16.2, 26.2, 36.2 and 47.6 cm. The boron-in-polyethylene spherical shells were pressed with powder of boron carbide and polyethylene. In three sets of boron-in-polyethylene samples the mass percentages of boron carbide were 0, 10% and 50%, respectively, corresponding to the average densities of 0.802±0.016, 0.856±0.017 and 1.259±0.030 g/cm^3. The iron samples only have inner two shells with the density of 7.8 g/cm^3.

The neutron source was obtained by the T(d, n)^{4}He reaction with an 150 keV deuteron beam produced by the 200 kV neutron generator at Institute of Nuclear Physics and Chemistry. Tritium target was placed at the centre of spherical shells. The neutron yield on the tritium target was monitored by counting the associated alpha particles with a Au-Si surface-barrier detector located at an angle of 177° from the deuteron beam line and a distance of 43 cm from the target.

The proton recoil method was used to measure the neutron energy spectra. The neutrons of above 1 MeV were detected using a NE-213 organic liquid scintillator and those of below 1.5 MeV by three spherical proportional counters filled with gas H_2 or CH_4 at different pressures. The pulse shape discrimination was employed to eliminate the gamma ray background. The details on the electronic system for data collection and process were published elsewhere.[2]

Measured proton-recoil pulse hight spectra were unfolded to obtain neutron energy spectra using neutron response matrix calculated by Monte-Carlo techniques for each detector.

3 Results

The neutron spectra from D-T source and the leakage spectra from various samples with

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different thicknesses and materials were measured respectively and normalized to the same alpha counts. The leakage probability is defined as

$$S(E) = \Phi(E) / \int_{\text{peak}} \Phi_0(E) \mathrm{d}E \qquad (1)$$

where $\Phi_0(E)$ is the energy spectrum for source and $\Phi(E)$ for sample; integral leakage is

$$T_i = \int_{E_i}^{E_{max}} S(E) \mathrm{d}E \qquad (2)$$

where E_{max} is maximum energy of measured spectra and E_i lower cut-off energy of the integral; removal cross section per unit mass (cm^2/g) is

$$\Sigma_i / \rho = -\frac{1}{L} \ln T_i \qquad (3)$$

where ρ(g/cm^3) is the density of sample, L(g/cm^2) the mass thickness of spherical shell assembly.

Table 1 Removal cross sections per unit mass (cm^2/g)

	$-CH_2-$		$-CH_2-$ +10% B_4C	$-CH_2-$ + 50% B_4C	Iron	
	This work	LLNL	This work	This work	This work	LLNL
$E_n \geq 10$ MeV	0.07576	0.0778	0.07574	0.05287	0.0160	0.0153
	±0.00105	±0.0022	±0.00031	±0.00046	±0.0004	±0.0003
$E_n \geq 7$ MeV	0.06433	–	0.06527	0.04546	0.01588	–
	±0.00076		±0.00071	±0.00060	±0.00048	
$E_n \geq 2$ MeV	0.0476	0.0504	0.04926	0.03472	0.01032	0.0103
	±0.0008	±0.00760	±0.00074	±0.00062	±0.0004	±0.0012
$E_n \geq 20$ MeV	0.03236	–	0.03770	0.02614	–	–
	±0.00156		±0.00145	±0.00068		

Fig.1 shows the leakage spectrum from spherical iron with the thickness of 10 cm for 14 MeV neutrons. Table 1 gives the removal cross sections of various materials for different lower cut-off energy and the comparisons of our work with LLNL (Lawrence Livermore National Laboratory). In Table 2 the experimental values of integral leakage are compared with those of transport calculations performed by Lu Ren-Bao[3] using direct integral method. As can be seen from the tables, our data are in agreement with results of LLNL and R. B. Lu's calculation results within experimental errors. We also noticed that the neutron shielding properties of the boron-in-polyethylene with 10% mass fraction boron carbide are better than those of others.

Table 2 Comparison between measured and calculated integral leakages for iron of 10 cm thickness

	Exp.	Cal.	Exp./Cal.
$E_n \geq 10$ MeV	0.2843±3%	0.29746	0.956
$E_n \geq 7$ MeV	0.2965±3%	0.30728	0.965
$E_n \geq 0.9$ MeV	0.6758±4%	0.6524	1.036

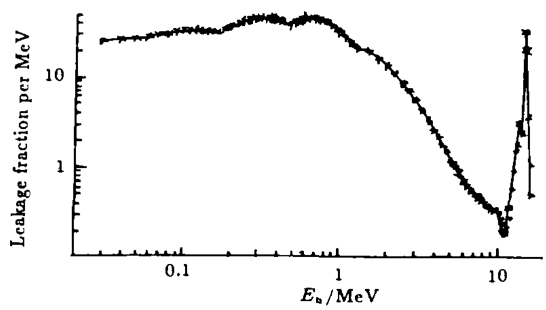

Fig.1 Leakage spectrum of D-T neutrons from iron shell of 10 cm thickness

References

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3 Lu Ren-Bao. Chinese Journal of Nuclear Science and Engineering, 1990; 10:97

Zhou Yu-Qing, Professor, has been engaged in research work on neutronics and highly stripped state ionic spectroscopy.