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The benchmark experiment on slab beryllium with D–T neutrons for validation of evaluated nuclear data

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HIGHLIGHTS

- Evaluated data for beryllium are validated by a high precision benchmark experiment.
- Leakage neutron spectra from pure beryllium slab are measured at 61° and 121° using time-of-flight method.
- The experimental results are compared with the MCNP-4B calculations with the evaluated data from different libraries.

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ABSTRACT

Beryllium is the most favored neutron multiplier candidate for solid breeder blankets of future fusion power reactors. However, beryllium nuclear data are differently presented in modern nuclear data evaluations. In order to validate the evaluated nuclear data on beryllium, in the present study, a benchmark experiment has been performed at China Institution of Atomic Energy (CIAE). Neutron leakage spectra from pure beryllium slab samples were measured at 61° and 121° using time-of-flight method. The experimental results were compared with the calculated ones by MCNP-4B simulation, using the evaluated data of beryllium from the CENDL-3.1, ENDF/B-VII.1 and JENDL-4.0 libraries. From the comparison between the measured and the calculated spectra, it was found that the calculation results based on CENDL-3.1 caused overestimation in the energy range from about 3–12 MeV at 61°, while at 121°, all the libraries led to underestimation below 3 MeV.

1. Introduction

Beryllium is an important material in fission and fusion nuclear technology for multiplying neutrons in the core of fission research reactors and in the blankets of D–T (deuteron–tritium) fusion reactors. A series of integral 14 MeV neutron experiments on beryllium assemblies have been conducted [1–3] to provide the experimental data base for qualifying and validating the beryllium nuclear data. However, the evaluated beryllium nuclear data from different libraries still show some differences for reaction cross sections and secondary particle emission spectra [4,5].

In order to validate the nuclear data for beryllium, the leakage neutron spectra from pure beryllium slab samples (5 cm and 11 cm thick) were measured between 0.8 MeV and 15 MeV by using the time-of-flight (TOF) technique. The results were compared with the calculations using the Monte Carlo code MCNP-4B [6].

2. Experimental setup

The measurements were performed by using the benchmark experimental facility at China Institute of Atomic Energy (CIAE). A schematic view of the experimental arrangement is shown in Fig. 1, which was described in detail earlier in [7–9].

2.1. The neutron source

The T(d, n)^{4}He reaction served as fusion neutron source. A tritium–titanium (T–Ti) target with an active diameter of 16 mm on a 0.5 mm thick molybdenum (Mo) backing was bombarded by a 300 keV deuteron beam. The thickness of the T–Ti target was about 1 mg/cm^2. The D$^+$ beam was bunched about 2.5 ns width in Full Width at Half Maximum (FWHM) and the repetition rate was

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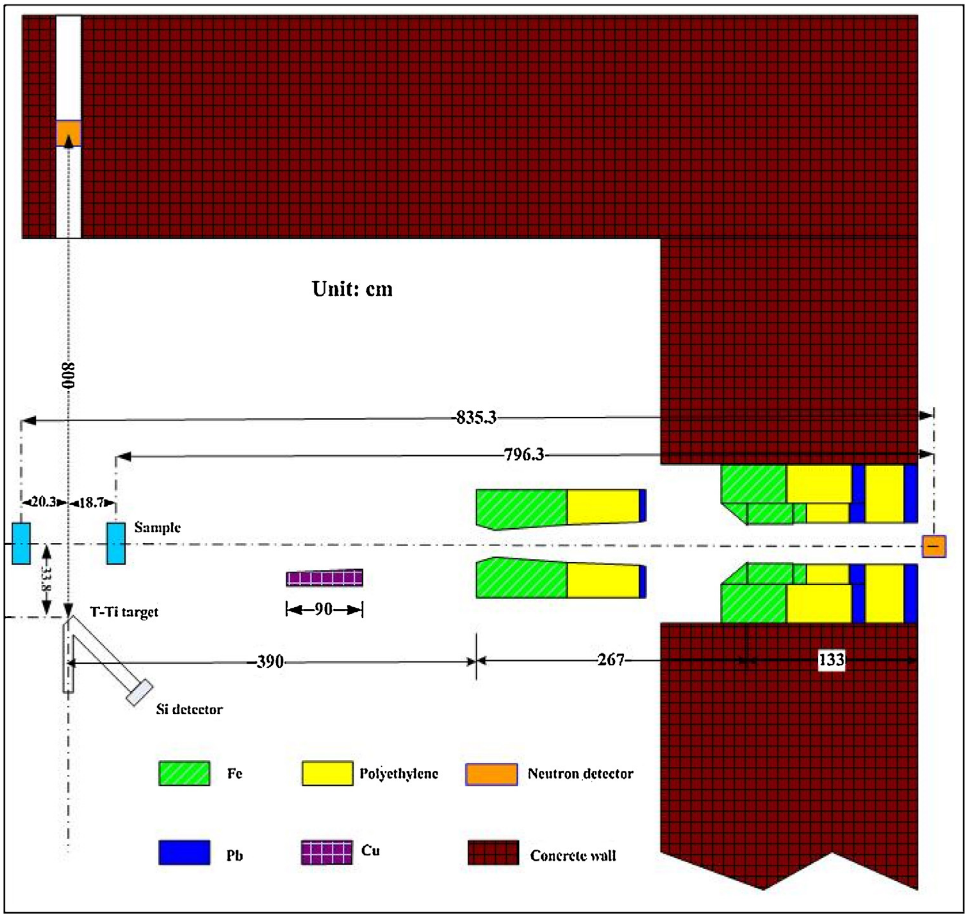

Fig. 1. Experimental arrangement for measuring the neutron leakage spectra from beryllium slab. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
The compositions of the sample (in weight).

Be	O	C	Fe	Al	Si
99.3%	0.52%	0.0224%	0.12%	0.02%	0.05%

Mg	Ni	Cr	Mn	Cu
0.012%	0.0048%	0.0034%	0.006%	0.012%

1.5 MHz. The beam current was about 30 μA, and the average neutron yield was about 2×10^9 n/s. An air-cooling device was used for cooling the target. A silicon detector, positioned at 135° with respect to the D^+ beam and 0.9 m from the target, was used to monitor the neutron yields by counting the associated ^{4}He particles. The source neutron yield was determined by the following Equations.

$$N_n = \frac{N_\alpha \times A_\alpha \times \sigma_{tot}}{\Delta\Omega \times \sigma(\theta)} \tag{1}$$

$$\Delta\Omega = \frac{\pi \times r^2}{L^2} \tag{2}$$

where N_α is the number of detected alpha particles, $\Delta\Omega$ is the solid angle of silicon counter, L is the distance from target surface to the silicon detector, r is the diameter of the silicon detector, A_α is the correction factor for detection solid angle, which is relevant to average deuteron beam energy and emission angle of alpha particles, σ_{tot} and $\sigma(\theta)$ are total and differential cross sections of the $T(d, n)^4He$ reaction, respectively. The term $\sigma_{tot}/\sigma(\theta)$ was used to correct the anisotropic effect of the d–T reaction neutron source.

A coefficient B was defined as:

$$B = \frac{A_\alpha \times \sigma_{tot}}{\Delta\Omega \times \sigma(\theta)} \tag{3}$$

For 300 keV incident deuteron energy, the associated alphas were detected at 135° and the neutron emission angle θ was 0°, A_α was determined to be 1.263. We obtained $B = 1.508 \times 10^6$ when $L = 90$ cm and $r = 0.16$ cm. The uncertainty was estimated to be less than 3%, which was mainly caused by the uncertainty of $\Delta\Omega$ and the statistical uncertainty of alphas, in which the statistical uncertainty of alphas (less than 1%).

2.2. The samples

All the beryllium samples used in the experiment had a square shape with 10 cm × 10 cm surface area, the slab thickness was chosen to be 5 cm and 11 cm, corresponding to 0.9 and 2 mean free path for 14.5 MeV neutrons, respectively. The sample purity and density were 99.3% and 1.84 g/cm^3, respectively. The sample compositions are listed in the Table 1.