Influence of thermal and resonance neutron on fast neutron flux measurement by ^{239}Pu fission chamber *

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Abstract: The ^{239}Pu fission chambers are widely used to measure fission spectrum neutron flux due to a flat response to fast neutrons. However, in the meantime the resonance and thermal neutrons can cause a significant influence on the measurement if they are moderated, which could be eliminated by using ^{10}B and Cd covers. At a column enriched uranium fast neutron critical assembly, the fission reaction rates of ^{239}Pu are measured as 1.791×10^{-16}, 2.350×10^{-16} and 1.385×10^{-15} per second for 15 mm thick ^{10}B cover, 0.5 mm thick Cd cover, and no cover respectively, while the fission reaction rate of ^{239}Pu is rapidly increased to 2.569×10^{-14} for a 20 mm thick polythene covering fission chamber. The average ^{239}Pu fission cross-section of thermal and resonance neutrons is calculated to be 500 b and 24.95 b with the assumption of $1/v$ and $1/E$ spectra respectively, then thermal, resonance and fast neutron flux are achieved to be 2.30×10^{6}, 2.24×10^{6} and 1.04×10^{8} cm$^{-2}\cdot$s^{-1}.

Key words: fission chamber, neutron flux, thermal and resonance neutrons, fast neutrons

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1 Introduction

Neutron flux is a very important data for neutron sources. Many studies focus on neutron flux [1, 2]. Fission chambers are widely used in online neutron flux measurement. It could be adopted for not only the fission neutron field but also the fusion neutron field [3]. Because the fission fragment signal in chambers with a large reaction energy of about 200 MeV is larger than those of the competing reaction and γ-rays, this facilitates n-γ discrimination. Also there are many studies about the background of fission chambers [4]. Moreover, the fission cross-sections above 10 keV of ^{239}Pu change insignificantly, often by less than 5% when the neutron energy is between 10 keV and 5 MeV. As a result, ^{239}Pu fission chambers are usually adopted to measure fast neutron flux [5].

A large cross-section of a few thermal and resonance neutrons contributes most fission reaction in the chamber: the fission rate changes sharply within a small range of fractions of thermal and resonant neutrons. The average fission cross-section of ^{239}Pu for fast neutrons is 1.72 b. The fission cross-section of ^{239}Pu at thermal neutrons (at the energy of 0.025 eV) is 744 b, which is larger than 1.72 b. Additionally, the ^{237}Np fission rate ratio relative to the ^{235}U fission rate per atom was measured to be 0.00439 to 0.0298 at Kyoto University Critical Assembly at five thermal cores [6]. Therefore the effect of thermal and resonance neutrons should be considered at measurements of fast neutron flux. The effect due to thermal and resonance neutrons is eliminated by the use of ^{10}B and Cd covers.

Neither moderator materials nor reflective materials currently exist in Godiva or Flattop type fast critical assembly [7]. The ionization chamber also has a lot of room for improvement. For example, we can change the structures, materials and so on to improve the ability of the ionization chamber [8]. The CERN built a new ionization chamber with fast timing properties for the measurement of the cross-section which particularly focused on fast time response, the good background rejection capability, low-background and high detection efficiency [9]. In this work we choose the ^{239}Pu fission chamber which is always used to measure fast neutron flux of critical assembly with Cd cover and ^{10}B cover to absorb thermal neutrons and resonance neutrons, and small concentrations of ^{241}Pu and ^{242}Pu can be tolerated. In this report, we focus in particular on the improvement of neutron flux measurement accuracy by the fission chamber.

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2 Experiment measurements

2.1 Detector system

The measuring system consists of a ^{239}Pu fission chamber, a preamplifier, a linear amplifier, and a multi-channel pulse analyzer. The fission chamber current pulse depends on specifications such as the filling gas pressure and the fission chamber geometry [10]. In the fission chamber, 0.168 mg ^{239}Pu is uniformly plated on a foil surface with a length of 10 mm and a width of 13.8 mm filled with 4.0×10^5 Pa argon. The broad side rolled into a round is placed inside the copper tube with the outer diameter of 6 mm and the inner 4.5 mm, as shown in Fig. 1. The fission chamber was fixed at an identical position at the four measurements.

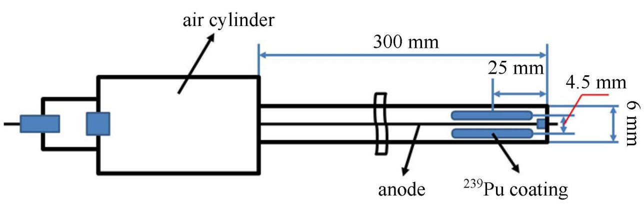

Fig. 1. Schematic diagram of the fission chamber.

2.2 Neutron spectrum of the critical assembly

The experiments were carried out in a ^{235}U metal fast critical assembly. In the fast neutron energy region of the reactor, the neutron spectrum is a slightly moderated fission spectrum. The calculated neutron spectrum of the critical assembly is shown in Fig. 2. The average neutron energy is 1.42 MeV.

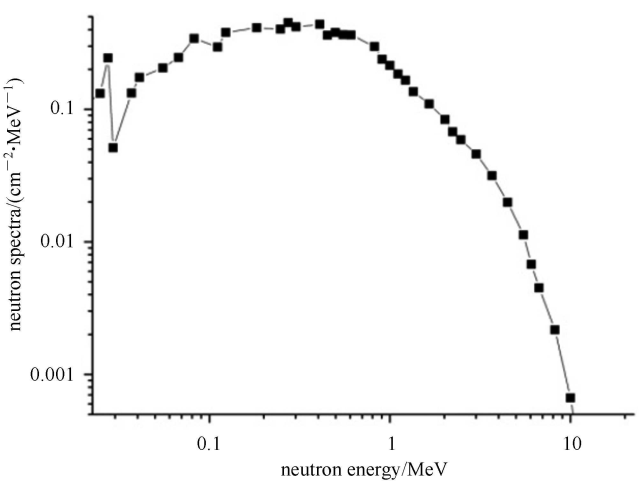

Fig. 2. Neutron spectrum of the uranium fast neutron critical assembly.

For further analysis, the neutron spectrum is divided into three groups. The thermal neutron region, $E_{\rm n}<1$ eV, is assumed to be $1/v$ spectrum. The resonance neutron region, 1 eV< $E_{\rm n}$ <10 keV, is assumed to be $1/E$ spectrum. The fast neutron group, $E_{\rm n}$ >10 keV, is assumed to be a slightly moderated fission spectrum. The calculated spectrum contains almost zero thermal neutrons, 0.06% of the resonance neutrons, and 99.94% of the neutrons with energy above 10 keV, which has 3.3% of neutrons with energy above 5 MeV. The structural material around the assembly is not taken into consideration in the calculation of neutron spectrum. In fact, there are often a few thermal neutrons and resonance neutrons for the moderation of the structural material. These neutrons contribute to most reactions in the ^{239}Pu chamber despite a little fraction.

2.3 Experiments

The ^{239}Pu fission chamber was fixed at the same position at four measurements, with a high voltage of 210 V, and the critical assembly operating at 180 W. The ^{239}Pu fission fragments spectra were recorded by MCA. (a) the fission reaction rate of the naked ^{239}Pu fission chamber was measured; (b) the reaction rate of the ^{239}Pu fission chamber with a 0.5 mm thick Cd cover was measured; and (c) the reaction rate of the ^{239}Pu fission chamber with ^{10}B cover was measured. The length of ^{10}B cover is 100 mm,with the hollow length, the inner diameter and the outer diameter being 85 mm, 10 mm and 40 mm respectively. There is a 0.5 mm cadmium skin at the internal of the ^{10}B cover. The effective cross-section of ^{239}Pu with ^{10}B cover is calculated as follows:

$$\sigma_{\rm eff}(E)=\sigma(E){\rm e}^{-\sigma_{\rm B}(E)N}. \tag{1}$$

Where: $\sigma_{\rm eff}$ is the ^{239}Pu effective cross-section, $\sigma(E)$ is the ^{239}Pu fission cross-section, $\sigma_{\rm B}(E)$ is the ^{10}B cross-section and N is the nuclei number of ^{10}B per unit area.

According to the calculations, the thermal neutron can be absorbed nearly 100% through 0.5 mm Cd skin and the resonance neutron can be absorbed more than 97% with 15 mm ^{10}B skin.

In order to investigate the influence of thermal neutrons on the measurements, the fission reaction rate of the ^{239}Pu fission chamber with a polythene cover was measured. The polythene cover is 19 cm in length, 17 cm in hollow length, 8 cm in outer diameter and 4 cm in inner diameter.

3 Results and discussions

The fission rate is calculated as follows:

$$\dot{F}=N\varphi\bar{\sigma}\eta. \tag{2}$$

η is the detection efficiency of the fission fragments where $\eta=1$, N is the number of the ^{239}Pu, φ is neutron flux, and $\bar{\sigma}$ is the average cross-section.

3.1 Results of the experiments

Figure 3 shows the measured fission fragments spectrum of the fission chamber. The double peaks in Fig. 3 correspond to light and heavy fission fragments. The peaks of two fission fragments are clearly separated and α pulses are shown in the low energy region. A lower platform between the α and the fragments is shown in the enlarged view in Fig. 3. The α and fission fragments can be well distinguished. The lower platform is extrapolated to take the fission fragments counts at the low-energy.

The measured reaction rates for the ^{239}Pu fission chamber at four states are shown in Table 1.

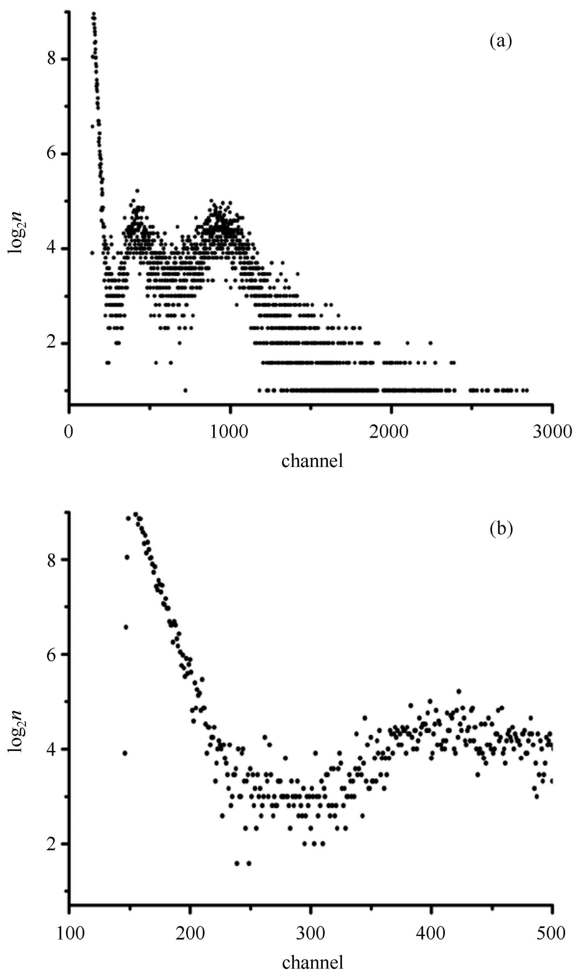

Fig. 3. (a) Fission fragment spectrum; (b) Platform enlarging.

Table 1. Reaction rates of the ^{239}Pu fission chamber with different covers.

fission chamber	^{10}B cover	cadmium cover	naked	polythene cover
reaction rate/$\times 10^{-16}$s^{-1}	1.791	2.350	13.85	256.9

3.2 Discussions

The cadmium ratio of ^{239}Pu in the fast neutron critical assembly is 5.89 indicating that the neutrons beyond 1 eV contribute to 17.0% (1/5.89) of the reaction rate. The thermal neutron spectrum is usually treated as the $1/v$ spectrum. Then the ^{239}Pu average cross-section for the thermal neutrons is calculated to be 500 b based on this assumption. Then the thermal neutron flux is measured to be 2.30×10^{6} s^{-1}cm^{-2}.

The ^{10}B cover absorbs the neutrons below 10 keV. After the absorption of the resonance neutrons by the ^{10}B cover, the effective cross-section of (n, f) drops. The ^{10}B cover affects the fission rate of ^{239}Pu mainly by absorbing the neutrons below 10 keV. Using the calculated neutron spectrum, the cross-section of the ^{239}Pu (n, f) reaction and the ^{10}B (n, α) reaction from the ENDF/B-VII.1 database, the average effect cross-section of ^{239}Pu (n, f) reaction is to be 1.72 b as neutron energy is beyond 10 keV. Then the fast neutron flux beyond 10 keV is 1.04×10^{8} s$^{-1}\cdot$ cm^{-2}.

The resonance neutron (energy between 1 eV and 10 keV) spectrum generally uses $1/E$ spectrum. Then the average cross-section in the resonance energy region is calculated to be 24.95 b. The resonance region neutron flux can be determined to be 2.24×10^{6} s$^{-1}\cdot$ cm^{-2}. The total neutron flux is 1.09×10^{8} s$^{-1}\cdot$ cm^{-2}, where the thermal, resonance and fast neutrons are 2.1%, 2.1% and 95.8% respectively, yet the reaction contribution fractions are 83.0%, 4.1%, and 12.9% respectively. Table 2 shows the neutron flux rate in different energy regions.

Table 2. Neutron flux rate in different energy regions.

energy region	neutron flux/ (s$^{-1}\cdot$cm^{-2})	fraction	contribution to the reaction rate
<1 eV	2.30×10^{6}	2.1%	83.0%
1 eV<E_n<10 keV	2.24×10^{6}	2.1%	4.1%
>10 keV	1.04×10^{8}	95.8%	12.9%

As the quotient of thermal neutrons increases, the reaction rate raises sharply. When the fission chamber is covered by 2 cm thick polythene, the reaction rate of ^{239}Pu increases to 2.569×10^{-14} s^{-1}, which is 18.5 times reaction rate of the bare ^{239}Pu fission chamber. We calculate the neutron spectrum after the moderation by the 2 cm thick polythene, obtaining that thermal, resonance and fast neutrons are 2.4%, 10.6% and 87.0% respectively. According to the total neutron flux the reaction rate is 1.757×10^{-15} s^{-1}, and thermal, resonance and fast neutrons contribution fraction are 74.4%, 16.3% and 9.3%. It is much smaller than 2.569×10^{-14} s^{-1}. Because the structural material around the assembly is not taken into consideration in the calculation, the thermal neutrons are zero. Actually, there are often a few thermal neutrons and resonance neutrons for the moderation of the structural material. The difference between the calculation and the experiment can also reveal the great impact of the thermal and resonance neutrons.

The ^{239}Pu fission chamber is very sensitive to thermal and resonance neutrons. Therefore, the measurement for neutron flux of the slightly moderated fission spectrum by the ^{239}Pu fission chamber can be divided into three sections: (a) use the bare ^{239}Pu fission chamber to measure the total neutron reaction contribution; (b) use the ^{239}Pu fission chamber covered by ^{10}B to measure the fast neutron flux; (c) use the ^{239}Pu fission chamber covered by Cd to measure the reaction rate while obviating thermal neutrons. Finally the thermal, resonance and fast neutron flux can be measured respectively.

4 Conclusions

On the assumption that the resonance neutron spectrum and the thermal neutron spectrum satisfy $1/E$ and $1/v$ distribution respectively, using a bare, a Cd-covered and a ^{10}B-covered ^{239}Pu fission chamber separately, the thermal, resonance and fast neutron flux can be measured. The thermal, resonance and fast neutron flux are achieved to be 2.30×10^6, 2.24×10^6 and 1.04×10^8 $\text{cm}^{-2}\cdot\text{s}^{-1}$ at a Godiva or Flattop type critical assembly; and the proportion of thermal, resonance and fast neutrons are 2.1%, 2.1%, and 95.8%; but the reaction contribution proportion are 83.0%, 4.1% and 12.9%.

Since the cross-section of thermal neutrons is much greater than that of the fast neutrons, a slight change of thermal neutrons will lead to large variation in the reaction rate. For this reason the neutrons of fast critical assemblies can be divided into three sections to measure the neutron flux by ^{239}Pu fission chamber. The result shows that the bare, Cd-covered and ^{10}B-covered fission chambers can be used to measure the three region neutron flux.

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