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Analysis and comparison of monoenergetic fast neutron fluence determination using ^{238}U samples at different positions with respect to the neutron source

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ABSTRACT

Using two ^{238}U samples placed in a gridded ionization chamber and a parallel-plate fission chamber, fluence of monoenergetic fast neutrons was determined. Four runs of measurements were performed. Analysis showed that although the neutron fluences for the two ^{238}U samples differ by 20–33 times in the present work, the fluences at the position of the sample in the gridded ionization chamber determined by the two ways are in agreement within experimental uncertainties.

1. Introduction

Neutron induced nuclear reaction data are extensively used in the investigations of radiation damage, nuclear heating, tritium breeding and neutron multiplication. These data are also necessary in nuclear model calculations to better understand nuclear reaction mechanisms. In our previous works, cross sections and/or differential cross sections were measured for fast neutron induced (n, α) reactions of a series of nuclei including light, medium mass and heavy ones (Gledenov et al., 2010, 2009; Zhang et al., 2010a, 2010b, 2008a, 2008b, 2007a, 2006). In our measurements, back-to-back samples and twin gridded ionization chambers were used to detect alpha particles from the (n, α) reactions and a ^{238}U sample was applied for monoenergetic fast neutron fluence determination by counting the fission fragments from the ^{238}U(n, f) reaction.

According to our experimental condition, the ^{238}U sample was placed either inside the gridded ionization chamber at the position of the sample with a sample changer (Zhang et al., 2008a, 2008b, 2007a, 2006) or in a small parallel-plate fission chamber near the neutron source (Gledenov et al., 2010, 2009; Zhang et al., 2010a, 2010b). In the former case, the neutron fluence was measured directly at the position of the sample, while in the latter case it was measured by the fission chamber close to the neutron source and the fluence inside the gridded ionization chamber at the sample position was calculated accordingly. The present work was performed to analyze and compare the results of the two ways of fast neutron fluence determination.

2. Experiments and expressions

2.1. Details of experiments

The experiments were performed at the 4.5 MV Van de Graaff accelerator of Peking University. The apparatus placed in the neutron hall is illustrated in Fig. 1 which consists of three parts: the fast neutron source, ^{238}U samples and fission detectors, and the neutron flux monitor.

Fast neutrons were produced through the ^{2}H(d, n)^{3}He reaction with a deuterium gas target bombarded by the deuteron beam. The length of the gas cell was 2.00 cm and the deuterium gas pressure was about 3.0 atm. The neutron energy was determined by the energy of the deuteron beam from the accelerator. Two neutron energies (E_n=4.0 and 5.0 MeV with energy spreads 0.23 and 0.16 MeV, respectively) were used in the present work. Details of the neutron source can be found in our previous papers (Gledenov et al., 2009; Zhang et al., 2010a).

Two circular ^{238}U samples were employed whose parameters are listed in Table 1. The numbers of the ^{238}U nuclei in the two

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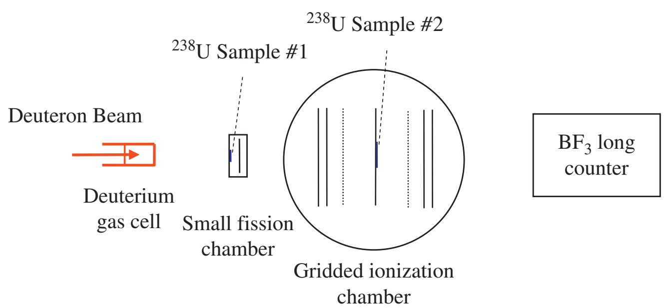

Fig. 1. Experiment apparatus.

Table 1
Parameters of the two circular shape ^{238}U samples.

Parameters	Sample #1	Sample #2
Sample radius (cm)	1.00 ± 0.01	2.25 ± 0.02
Sample material	$^{238}U_3O_8$	$^{238}U_3O_8$
Enrichment of ^{238}U isotope (%)	99.997	99.999
Mass of ^{238}U (μg)	547.2 ± 7.1	7850 ± 100
Number of ^{238}U nuclei	$1.384 \times 10^{18} \pm 1.3\%$	$1.985 \times 10^{19} \pm 1.3\%$

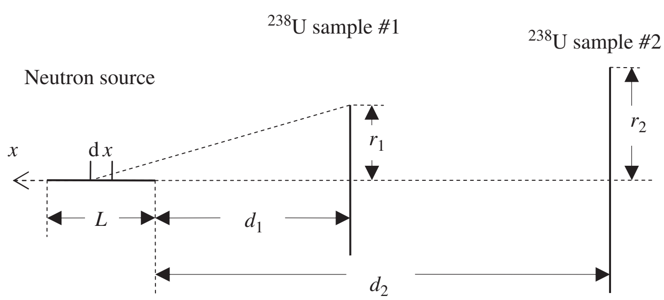

Fig. 2. Geometry of the neutron source and the ^{238}U samples (not to scale).

samples were measured by counting the alpha activity using two detectors: the gridded ionization chamber (with nearly 2π detection solid angle) and a silicon surface barrier detector (with a small solid angle). The results are in agreement within measurement uncertainty (1.3%) although their detection efficiencies differ by ~475 times.

The ^{238}U sample #1 was placed in the small fission chamber and the sample #2 was set at the sample position in the gridded ionization chamber. The working gas of the fission chamber and the gridded chamber was the mixture of Ar+3.73% CO_2. With a sample changer, the gridded ionization chamber was designed originally for alpha-particle detection from (n, α) reactions (Zhang et al., 2010b). Details of the gridded chamber (including electronics and data acquisition system) and the fission chamber can be found in Zhang et al. (2010b).

A BF$_3$ long counter was used as the neutron flux monitor and for normalization among different runs. The distance from the neutron source to the front side of the BF$_3$ long counter was about 2.4 m.

As shown in Fig. 1, the BF$_3$ long counter, the gridded ionization chamber and the fission chamber were set at 0° to the beam line. The axis of the counter tube was along the beam line whereas the electrodes of the ionization chamber and the fission chamber were perpendicular to the beam line.

The geometry of the neutron source and the two ^{238}U samples is illustrated in Fig. 2, in which the neutron source is treated as a uniform line source with length L=2.00 cm. Four runs of measurements were performed. The energy of neutrons, the distances from the two ^{238}U samples to the neutron source and the duration for each run in the measurement sequence are listed in Table 2. The deuteron beam current was ~2.5 μA throughout the measurement. The fission spectra from the two ^{238}U samples as well as the counts of the BF$_3$ long counter were recorded for all runs.

2.2. Expressions for neutron fluence determination

The purpose of our measurement is to determine the neutron fluence at the position of the sample in the gridded ionization chamber (i.e. ^{238}U sample #2 in Figs. 1 and 2). According to the definition of the cross section, the average neutron fluence for sample #2 can be obtained through the following equation:

$$\Phi_2 = \frac{N'_2}{\sigma_f N_{238U\#2}}, \tag{1}$$

where N'_2 is the number of fission counts from sample #2, $N_{238U\#2}$ is the number of ^{238}U atoms in it, and σ_f is the cross section of the ^{238}U(n, f) reaction taken from the ENFD/B-VII.0 library (ENDF, 2010) as listed in Table 3.

Alternatively, the average neutron fluence of the sample #2 can be calculated from that of the sample #1:

$$\Phi'_2 = \frac{\Phi_1}{K} = \frac{1}{K}\frac{N'_1}{\sigma_f N_{238U\#1}}, \tag{2}$$

where Φ_1 represents the average neutron fluence of sample #1, N'_1 is the number of fission counts from sample #1, $N_{238U\#1}$ is the number of ^{238}U atoms in it and K denotes the ratio of the average neutron fluences of sample #1 to sample #2. The value of K is determined by the geometry of the neutron source and the two ^{238}U samples as well as the angular distribution of the source neutron, with the following expression:

$$K = \frac{\int_0^L dx \int_0^{2\pi} d\varphi \int_0^{tg^{-1} r_1/(d_1+x)} \sin\theta\sigma(\theta)d\theta \; \pi r_2^2}{\int_0^L dx \int_0^{2\pi} d\varphi \int_0^{tg^{-1} r_2/(d_2+x)} \sin\theta\sigma(\theta)d\theta \; \pi r_1^2}, \tag{3}$$

where L is the length of the deuterium target gas cell; r_1, r_2 and d_1, d_2 are the radii of the two ^{238}U samples and the distances from the gas cell to each of them, respectively (Fig. 2); and $\sigma(\theta)$ is the differential cross section of the ^{2}H(d, n)^{3}He reaction. Data of $\sigma(\theta)$ are shown in Fig. 3 (Drosg, 2003).

Values of K can be obtained from numerical calculations using Eq. (3). K values for all runs are listed in Table 3. The relative uncertainty of K mainly comes from that of d_1 as well as the beam position through the gas cell.

To compare the average neutron fluences Φ_2 and Φ'_2 from Eqs. (1) and (2), respectively, correction from the attenuation through the stainless steel wall of the gridded ionization chamber should be performed. The expression of the attenuation factor is

$$P = e^{-n\sigma_t d}, \tag{4}$$

where d is the thickness of the stainless wall (1.5 mm), σ_t is the total cross section and n is the number density of the nuclei in the material. Since this correction is small (i.e. values of P are close to unity), total cross section of ^{56}Fe (with abundance 91.754% in natural iron) was used instead of the value for the stainless steel.

Table 2
Neutron energy, distances of the two ^{238}U samples to the neutron source and the duration for each run of measurement.

Run number	E_n (MeV)	d_1 (cm)	d_2 (cm)	Duration (h)
1	5.0 ± 0.16	3.78 ± 0.05	20.95 ± 0.05	~2
2	5.0 ± 0.16	2.73 ± 0.05	20.95 ± 0.05	~2
3	4.0 ± 0.23	2.73 ± 0.05	20.95 ± 0.05	~3
4	4.0 ± 0.23	3.78 ± 0.05	20.95 ± 0.05	~3