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≪Technical Report≫ Measurement of the Fast Neutron Flux Density in the Bulk Shielding Experimental Tank of the TRIGA Mark-II Reactor Using Solid State Track Detector

Seung Gy Ro, Jae Shik Jun and Sae Hyung Cho*

Korea Atomic Energy Research Institute, Seoul, Korea
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Abstract

The horizontal distribution of the fast neutron flux density in the Bulk Shielding Experimental Tank of the TRIGA Mark-II reactor at the steady power of 250 KW has been measured using a solid state track detector which is natural mica placed in contact with ^{232}Th fissile foil.

The neutron flux density was calculated on the assumption that the fast neutron spectrum is similar to that from the thermal-induced ^{235}U fission. The resulting flux density distribution along the horizontal line from the center of the thermalizing column door is presented in tabular and graphical forms.

요 약

^{232}Th 핵분열 물질과 조합된 고체비적검출체를 사용하여 250 KW로 정상운전되는 TRIGA Mark-II 원자로의 대차폐수조내에서 열중성자주(thermalizing column)의 중심으로부터 수평방향의 속 중성자 선속밀도 분포를 측정하였다.

속 중성자 스펙트럼이 ^{235}U가 열 중성자에 의하여 핵분열이 일어날때 방출되는 중성자 스펙트럼과 같다는 가정을 한 다음, 선속밀도는 고체비적검출체로 얻어진 실험결과로부터 계산되었다. 이와 같은 방법으로 속 중성자 선속밀도 분포의 측정 결과는 도표로서 제시된다.

1. Introduction

This study is an extension of the earlier works[1, 2] in which thermal neutron measurements were exclusively made, in view of ever increasing demand.

The reliable determination of the fast neutron flux density depends upon an *a pricri* knowledge of the spectrum. The accurate determination of the spectrum is by no means simple. Although various suggestions have been so far made for measuring it, no rigorous method has been found yet. Furthermore, it is hardly possible to measure the spectrum accurately in such a neutron environment as is in the Bulk Shielding

* Now in Hong Ik University.

Experimental Tank (BSET) where is low in the neutron flux density. When sufficient data are lacking, an assumption on the spectrum is generally accepted.

Assuming that the spetrum may approximate to that from the thermal-induced ^{235}U fission in this study[3], an interpretation of neutron flux densities was made from the experimental data obtained by the mica solid state track detector, which is commonly referred to as SSTD, in combination with ^{232}Th fissile foil. In this way, a variation of the fast neutron flux densities was determined as a function of distance in water from the center of the thermalizing column door.

2. Theoretical Background

The experimental data obtained by a SSTD in combination with a charged particle emitter may be expressed in the form:

$$H=\varepsilon PdN\int_0^\infty \sigma(E)\phi(E)dE \qquad (1)$$

indicating total number of tracks, H, per second for a thin charged particle emitter foil with a thickness of d in the differential neutron flux density $\phi(E)$. The term "thin" means that the foil is thinner than the range R of charged particle in its emitter. For a foil thick relative to the range, d in Eq. (1) should be replaced by R. The average range of fission fragments is approximately 10mg/cm^2 corresponding to about 8μm in ^{232}Th[4], where

N: number of atoms under consideration,
$\sigma(E)$:differential reation cross section,
ε: track registration efficiency of the SSTD for the 2π geometry,
P: escape probability of charged particles from their emitter (for thick fission fragment emitter, $P=1/2$)[8].

The track registration efficiency ε is often written in the form

$$\varepsilon=1-\sin\theta_c \qquad (2)$$

Here θ_c is termed the "critical angle" of chemical etching in the SSTD for the type and energy of the radiation concerned. According to the work of Khan and Durrani[5], θ_c for the mica SSTD is given by 4°30′, leading to 92.2% in ε.

In the case where one particle emitter is employed for the measurement of neutron flux densities, it is customary to make physical assumptions about the neutron spectrum. Otherwise it is impossible to measure them. For the assumed spectrum, Eq. (1) can be thus written by

$$H=\varepsilon PdN\phi\int_0^\infty \sigma(E)F_a(E)dE \qquad (3)$$

in which ϕ is the integrated neutron flux density, and $F_a(E)$ is the assumed spectrum. Further, Eq. (3) can be simplified as follows:

$$H=\varepsilon PdN\bar{\sigma}\phi \qquad (4)$$

if $\int_0^\infty F_a(E)dE$ is normalized to be 1. Here $\bar{\sigma}$ is represented by

$$\bar{\sigma}=\frac{\int_0^\infty \sigma(E)F_a(E)dE}{\int_0^\infty F_a(E)dE} \qquad (5)$$

For the fission neutron spectrum[3] and the ^{232}Th fission fragment emitter $\bar{\sigma}$ is given by (70.2±13.5) mb.[6]

The total number of tracks at the end of irradiation, H_t, is then

$$H_t=\varepsilon PdN\bar{\sigma}\phi t \qquad (6)$$

where t is the irradiation time, and ϕt is often called neutron fluence or time-integrated neutron flux density. If a foil thick with regard to the range R of charged particles in its emitter is employed as in the case of this work, d in Eq. (6) should be replaced by R.

3. Experimental Procedure

The domestically produced mica SSTDs were selected on the basis of clarity and low number of "fossil" tracks for use in this study.

The pre-etched mica strips that were typi-

Table 1. Some physical and nuclear properties of fissile foils

	^{232}Th	^{238}U*
Thickness(cm)	0.0051	0.0051
Weight (g)	0.0775	0.1107
Purity (%)	99.885	99.935
Diameter(cm)	1.27	1.27
Fission cross section(mb)[a]	70.2±13.5	285±27
Spontaneous fission (fissions/g/sec)[b]	$+3.33\times10^{-4}$	6.90×10^{-3}

* Depleted to 0.22% ^{235}U.
[a] From the work of Bak and Lorenz(Ref. 6).
[b] Taken from Ref. 7.
[+] Data given in Ref. 7 show a large diversity. Among them the highest value was taken here.

cally 2cm in diameter by about 0.01cm thick were placed next to thick ^{232}Th fissile foil. Henceforward, the SSTD combined with the fissile foil will be called the "SSTD system". The ^{232}Th fissile foil together with ^{238}U which was used as an indicator of the spectral deviation was purchased from Reactor Experiments, Inc., USA and in Table 1 presented are some of their physical and nuclear properties.

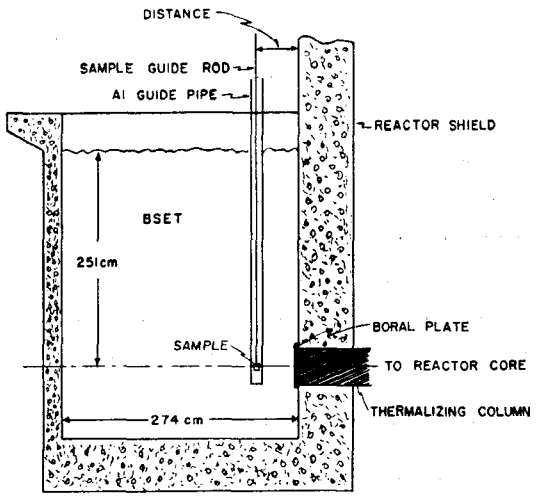

Fig. 1. Vertical section of bulk shielding experimental tank showing irradiation arrangement

The SSTD system was covered with 1mm thick cadmium in order to minimize the possible influence due to foreign fissile materials which may be contained in the ^{232}Th foil as unwanted impurities, and subjected to irradiation at several positions along the horizontal line up to 50cm from the center of the thermalizing column door in the BSET facility (ref. to Fig. 1). The experimental details including sample irradiations, chemical etching and track countings are the same as described in the previous work[2].

The reactor with which this work is concerned was operated at the steady power of 250 KW.

4. Results and Discussion

In Table 2 presented are results of fast neutron measurements at various positions in the BSET facility using the mica SSTD coupled with the thick ^{232}Th fissile foil. The errors quoted in total tracks were obtained from the common rules of Poisson statistics.

Even if "fossil" background tracks in the mica SSTD used here were discriminated by the pre-etching technique,[8] there may possibly be a new background from the neutron-induced fission of trace amounts of fissile material contained in the mica as the impurity and from the spontaneous fission of ^{232}Th employed as a radiator of fission fragments. In order to know the influence due to the impurity in mica, ten pre-etched mica strips were subjected to irradiation in the neutron field which is characterized by 5.90×10^{11} n_f/cm^2 and 2.53×10^{10} n_f/cm^2 for thermal and fast neutron fluences, respectively. No noticeable tracks, however, were observed so as to be disregarded. The influence due to the spontaneous fission of ^{232}Th can be readily calculated from the data for the spontaneous fission rate. Unfortunately the data for it given in reference 7 show a diversity that makes it impossible

Table 2. Result of fast neutron measurements

Irradiation position (cm)	Irradiation time (hr)	Total tracks per cm^2	Neutron fluence (n/cm^2)	Neutron flux density (n/cm^2-sec)
16.5	1	587±53	(7.02±0.64)10^8	(1.95±0.18)10^5
20.0	2	837±64	(1.00±0.08)10^9	(1.39±0.11)10^5
30.0	12	1859±100	(2.22±0.12)10^9	(5.14±0.28)10^4
40.0	12	630±55	(7.54±0.66)10^8	(1.75±0.15)10^4
50.0	18	721±59	(8.62±0.70)10^8	(1.33±0.11)10^4

to deduce the influence accurately. Therefore, a preliminary attempt was made to determine experimentally background tracks due to the spontaneous fission. One mica strip was kept in direct contact with ^{232}Th fissile foil for 30 days, and then tracks produced were observed to be 61.8±8.5 tracks/cm^2-month. This value is in serious disagreement with expected values of 1.3×10^{-2} to 8.0 tracks/cm^2-month calculated on the basis of the data for the spontaneous fission rates[7]. The reason for this large discrepancy cannot be accounted at present, but will remain for consideration in future work. At any rate, its influence seems to be negligible under our experimental condition in which the longest duration of contact between the mica and fissile foil used here was 3 days. This makes it unnecessary to apply background correction to the total track counting data.

Putting total track counting data into Eq. (6), neutron fluence and flux density values were obtained, and the quoted errors were from the counting statistics only.

Fig. 2 shows the horizontal distribution of the fast neutron flux density drawn from the results given in Table 2. The error bars are indicated and solid line was drawn by a least-squares fitting in favor of the experimental data.

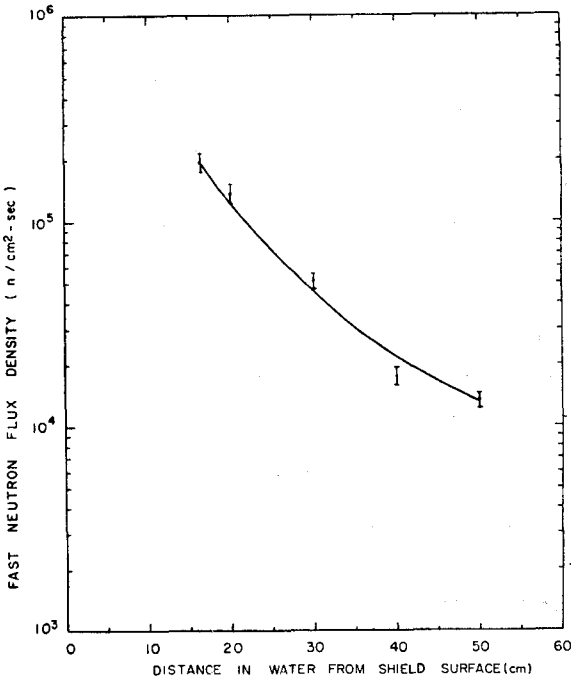

Fig. 2. Fast neutron flux density distribution in bulk shilding experimental tank of TRIGA Mark II reactor

A set of ^{232}Th and ^{238}U fissile foils was employed to obtain an information on the general trend of spectrum variations[9]. This can be known by observing their reaction ratios in terms of track density, even though the

Table 3. Reaction ratios of a set of ^{238}U and ^{232}Th foils in several positions of BSET

	^{235}U+thermal fission neutron	Reactor shield surface-to-detector distance (cm)				
		16.5	20	30	40	50
$\frac{H_U}{H_{Th}}$	3.5	17.0±1.2	4.3±0.4	3.5±0.3	3.1±0.3	2.0±0.3

accuracy may be poor. In Table 3 are listed the results obtained at several positions of the BSET facility. For comparison, the calculated reaction ratio for the thermal-induced ^{235}U fission spectrum is included in second column of the table. The reaction ratio is decreasing with increasing distance. At a glance, it may be said that the spectrum hardening occurs at a distance in water from the thermalizing column door.[9] It is, however, too dangerous to draw a conclusion because of the limited knowledge on the spectrum. Nevertheless, it is strongly suggested that the neutron spectra differ from position to position and that the interpretation method adopted in this work is not very plausible. Therefore, the data obtained in this study should be used temporary and will be reconsidered when the accurate information on the neutron energy spectrum is available.

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