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Determination of thermal neutron flux distribution

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1. Introduction

A D-D neutron generator [1], with an intensity of 10^8 n/s, will be used for education and researches by using the thermal neutron irradiation at Seoul National University. In this study, the distribution of thermal neutron flux obtained at the irradiation position is measured by Mn activation.

2. Method

The neutron generation rate is monitored by counting protons using the Si detector [2] and it fluctuates during the neutron irradiation. The neutron generation rate during Mn activation can be expressed as a function $R(t)$ of the time variable. It is assumed that the thermal neutron flux at the sample position is proportional to the neutron generation rate. A proportional constant C_{th} can be determined hence the thermal neutron flux can be expressed as the function of the time variable. When the bare and the Cd-covered sample are prepared separately and irradiated during different time period, C_{th} is determined by

$$C_{th} = \frac{A_{p,b}}{n_b \langle \sigma_a \rangle \varepsilon \Gamma \left(e^{-\lambda t_1} - e^{-\lambda t_2} \right)} \left\{ e^{-\lambda (T_2 - T_1)} \int_{T_1}^{T_2} e^{\lambda (t - T_1)} R(t) dt \right\}^{-1} - \frac{IC_{ep}}{\langle \sigma_a \rangle}$$

where $A_{p,b}$ is the γ-ray peak area of activated nuclide in the bare sample, n_b is the number of nuclide in the bare sample, $<\sigma_a>$ is the effective thermal neutron absorption cross section, ε is the γ-ray detection efficiency, Γ is the emission probability, λ is the decay constant, t_1 is the time after irradiation to detection-start, t_2 is the time after irradiation to detection-end, T_1 is the irradiation start time of the bare sample, T_2 is the irradiation end time of the bare sample, I is the resonance integral and C_{epi} is a proportional constant given by the following equation.

$$C_{epi} = \frac{A_{p,Cd}}{n_{Cd} I \varepsilon \Gamma \left(e^{-\lambda t_1} - e^{-\lambda t_2} \right)} \left\{ e^{-\lambda (T_4 - T_3)} \int_{T_3}^{T_4} e^{\lambda (t - T_3)} R(t) dt \right\}^{-1}$$

where $A_{p,Cd}$ is the γ-ray peak area of activated nuclide in the Cd-covered sample, n_{Cd} is the number of nuclide in the Cd-covered sample, T_3 is the irradiation start time of Cd-covered sample and T_4 is the irradiation end time of Cd-covered sample.

3. Determination of thermal neutron flux distribution

The geometry of the moderator is shown in Fig. 1 and the moderator is manufactured by a design based on the previous study [3]. The moderator is made of polyethylene. To determine the thermal neutron flux distribution inside the sample carrier, five Mn chips are installed as shown in Fig. 1. The natural abundance of ^{55}Mn is 100% and the activity is induced by ^{55}Mn(n,γ)^{56}Mn reaction. The half-life of ^{56}Mn is 2.5785 hours. The energies and emission probabilities of decay γ-rays of ^{56}Mn are 846.7 keV (98.9%), 1810.7 keV (27.2%), 2113.1 keV (14.3%), respectively. The sample carrier installed bare Mn chips and the sample carrier installed Cd-covered Mn chips are irradiated during the 11400 sec and 5400 sec, respectively. Weight of Mn chips and distance from the neutron generation target are shown in Table 1 and the thickness of Cd plate is 0.5 mm. Irradiated Mn chips are transferred by pneumatic transfer system to the γ-ray detection position in a lead cage which greatly suppresses background γ-rays. Decay γ-ray spectra are measured by using a HPGe detector.

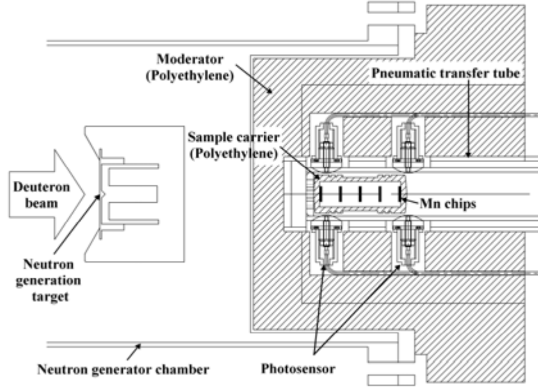

Fig. 1. Structure of the neutron moderator and position of Mn chips

Table 1. Weight of Mn chips and distance from the neutron generation target.

Position	Distance from neutron generation target [cm]	Weight [g]	
		Bare	Cd-covered
1	14.6	1.1335	0.8261
2	15.9	1.2729	0.7985
3	17.2	1.1487	0.8191
4	18.5	1.3151	0.8250
5	19.8	1.1897	0.8812

Neutron generation rate during the irradiation is shown in Fig. 2. The deuteron beam energy is 80 keV and the beam current is 8.6 mA. Separate linear fit is performed in each period of neutron irradiation. The fitting formulae of the irradiation period for bare and Cd-covered Mn chips are shown in Fig. 2. Calculated C_{th} and C_{epi} by using the peak area of 846.7 keV decay γ-line are shown in Table 2. The thermal neutron flux which is expressed as a first-degree polynomial function of the time variable and the average thermal neutron flux with respect to the irradiation period of bare Mn chips ($T_1 < t < T_2$) are shown in Table 3.

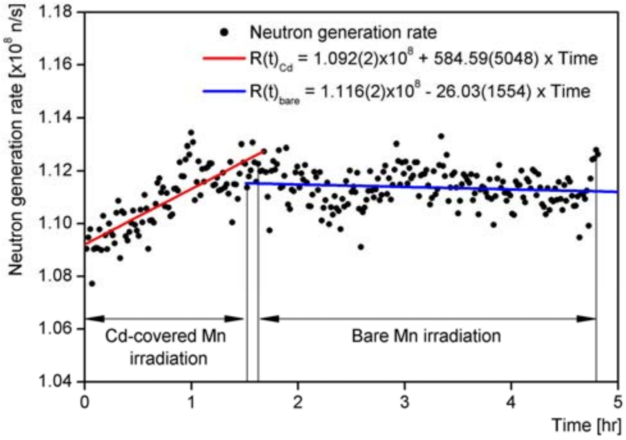

Fig. 2. Neutron generation rate and fitting formulae during the neutron irradiation period

Table 2. Calculated C_{th} and C_{epi} by using the peak area of 846.7 keV decay γ-line

Position	C_{th} [$\times 10^{-4}$ cm^{-2}]	C_{epi} [$\times 10^{-6}$ cm^{-2}]
1	2.53 ± 0.06	7.62 ± 0.42
2	2.49 ± 0.06	7.67 ± 0.48
3	2.16 ± 0.06	7.20 ± 0.47
4	1.98 ± 0.06	5.37 ± 0.41
5	1.84 ± 0.06	4.66 ± 0.36

Table 3. Determined thermal neutron flux with respect to the irradiation period of bare Mn chips

Position	$\phi_{th}(t)$		$\phi_{th,avg}$ [$\times 10^4$ n/cm^{2}s]
	y-intercept [$\times 10^4$ n/cm^{2}s]	gradient [$\times 10^3$ n/cm^{2}s^2]	
1	2.83 ± 0.07	-3.29 ± 1.97	2.82 ± 0.07
2	2.78 ± 0.07	-3.24 ± 1.93	2.77 ± 0.07
3	2.42 ± 0.07	-2.82 ± 1.68	2.41 ± 0.07
4	2.21 ± 0.07	-2.58 ± 1.54	2.20 ± 0.07
5	2.05 ± 0.07	-2.39 ± 1.43	2.05 ± 0.07

3. Conclusion and further work

The distribution of the thermal neutron flux is determined by Mn activation and it decreased gradually by the distance between the neutron generation target and Mn chip increased. When the D-D neutrons are generated at a rate around 10^8 n/s, the thermal neutron flux is about 10^4 n/cm^{2}s. The result of this study will be used as basic information to determine the sample irradiation time, the mass of sample and the sample irradiation position. Furthermore, the self-shielding effect of thick Mn chip will be considered for the determination of the thermal neutron flux.

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