Neutron Spectrum Measurement for d-Li Neutrons Using Activation Method

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We are carrying out a conceptual design activity of Advanced Fusion Neutron Source (A-FNS) facility, and are to perform radiation irradiation tests for fusion DEMO reactor materials in A-FNS[1)]. A-FNS produces a large number of neutrons via d-Li stripping reaction[2)] by bombarding a liquid lithium target with 40 MeV deuteron beam of 125 mA same as IFMIF[3)] projects. The enormous radiations should be measured and calculated precisely in A-FNS in order to evaluate the neutrons and photons indicate a DPA and ^{4}He production in the test specimen in the irradiation test module. As a candidate measurement method, we have proposed the neutron spectrum measurement system of A-FNS with neutron activation systems using water flow, and several activation monitors[4)]. Accurate dosimetry cross section data should be required for high precision measurement of the neutron spectrum using the activation method. However, the nuclear data libraries above 20 MeV neutrons are very limited. Although there are only two representative dosimetry cross section libraries, JENDL/D-99[5)] and IRDFF-1.05[6)], JENDL/D-99 is given in the neutron energy region below 20 MeV. Besides, an experimental data for a neutron-induced cross section in the high energy region above 20 MeV is also scarce. In order to verify the dosimetry cross sections and an applicability of the reactions as the neutron spectrum measurement above 20 MeV for A-FNS, we have performed an experiment of activation cross-section measurement on eight threshold dosimetry reactions with d-Li neutron source at CYRIC of Tohoku University.

Figure 1 shows a photograph of the experimental setup employed at the end of the 32-beam course of CYRIC. Along the beam line, the cylindrical solid lithium target of 25 mm in thickness and 20 mm in radius was set in a pure aluminum holder to prevent unnecessary long-lived activation products from the experimental apparatus. Several activation reactions were selected as the candidates based on its half-life, gamma intensity and handleability[4)]. The activation foils of Cobalt, Niobium, Gold and Bismuth were located at the positions of 0 cm, 5 cm, 10 cm distance from the aluminum holder, in order to measure the dosimetry reaction rates of the (n,p) and (n,xn) reactions. Table 1 shows the eight dosimetry reactions with the evaluable energy ranges in this experiment. In addition, two inclined panels with ± 30° were placed to measure the dosimetry reaction rates as a function of angle between the beam line and the foils, 6°, 22° and 38°, as shown in Fig. 2. The foils are in the form of pure metal with dimensions, 10.0 × 10.0 × 1.0 mm^3. The beam irradiation was performed for 5 hours with ~1.1 μA average beam current. After the irradiation, We measured the dosimetry reaction rates of ^{59}Co(n,p)^{59}Fe, ^{59}Co(n,2n)^{58}Co, ^{59}Co(n,3n)^{57}Co, ^{93}Nb(n,2n)^{92m}Nb, ^{197}Au(n,2n)^{196}Au, ^{209}Bi(n,3n)^{207}Bi, ^{209}Bi(n,4n)^{206}Bi and ^{209}Bi(n,5n)^{205}Bi reactions as functions of distances from the Li target holder, and angles between the beam line and foils to compare the calculation result of the reaction rate with the experiment ones due to differences of the neutron spectrum. The experimental analyses were performed using a Monte Carlo transport code, McDeLicious-11[7)] that has been developed as the extension code of MCNP5[8)] to simulate the d-Li neutron source. The latest fusion evaluated neutron data library, FENDL-3.1d[9)], was used for the transport calculation. The reaction rates of the activation foils were calculated using the dosimetry cross-section data library, IRDFF-1.05. Several reactions data are not included in IRDFF-1.05, and we used the data in FENDL/A-3.0[10)] for following reactions: ^{209}Bi(n,4n)^{206}Bi and ^{209}Bi(n,5n)^{205}Bi.

Figures 3 and 4 show the typical results of the experiment. The Cal./Exp. is the ratios of the calculated reaction rates of the reactions to the experimental ones at 5 cm distance from the surface of the Li target and at 38° angle between the beam line and the foils, respectively. The calculated reaction rates of ^{59}Co(n,2n)^{58}Co, ^{59}Co(n,3n)^{57}Co, ^{93}Nb(n,2n)^{92m}Nb, ^{197}Au(n,2n)^{196}Au and ^{209}Bi(n,3n)^{207}Bi reactions at 5 cm distance agree well the experimental one within 20%. The calculated reaction rates of ^{59}Co(n,p)^{59}Fe, ^{59}Co(n,2n)^{58}Co, ^{59}Co(n,3n)^{57}Co, ^{93}Nb(n,2n)^{92m}Nb, ^{197}Au(n,2n)^{196}Au, ^{209}Bi(n,3n)^{207}Bi and ^{209}Bi(n,4n)^{206}Bi reactions at 38° angle agree well the experimental one within 20%. As the results, the reactions can be applied to the A-FNS neutron spectrum measurement system for the high neutron energy region. However, the calculated reaction rate of ^{209}Bi(n,5n)^{205}Bi reaction underestimates the experimental one at 5 cm distance and overestimates the experimental one at 38° angle, respectively. Further investigation for the accuracy of FENDL/A-3.0 is necessary. In this study, it is indicated that the present dosimetry cross-section data of ^{59}Co(n,3n)^{57}Co, ^{197}Au(n,2n)^{196}Au, ^{209}Bi(n,3n)^{206}Bi, reactions in IRDFF-1.05 can be used for the A-FNS spectrum measurement system within ~20% of measurement accuracy. The reactions can cover the neutron energy range from 10 MeV to 45 MeV.

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Table 1. Measured dosimetry reactions.

Foil nuclide	Reaction	Measured nuclide	Half-life	Measured γ-ray energy [keV]	Intensity [%]	Neutron sensitivity [MeV]	Measuring Time [sec]
^{59}Co	(n,p)	^{59}Fe	44.5 d	1099.24	56.5	8<E<25	~150,000
	(n,2n)	^{58}Co	70.9 d	810.76	99.45	13<E<27	~150,000
	(n,3n)	^{57}Co	271.7 d	122.06	85.6	25<E<45	~150,000
^{93}Nb	(n,2n)	^{92m}Nb	10.2 d	934.44	99.07	11<E<22	~1,050
^{197}Au	(n,2n)	^{196}Au	6.2 d	355.73	86.95	10<E<20	~1,000
^{209}Bi	(n,3n)	^{207}Bi	32.9 y	569.70	97.75	20<E<30	~250,000
	(n,4n)	^{206}Bi	6.2 d	803.10	99.00	30<E<40	~4,600
	(n,5n)	^{205}Bi	15.3 d	703.45	31.10	40<E<55	~250,000

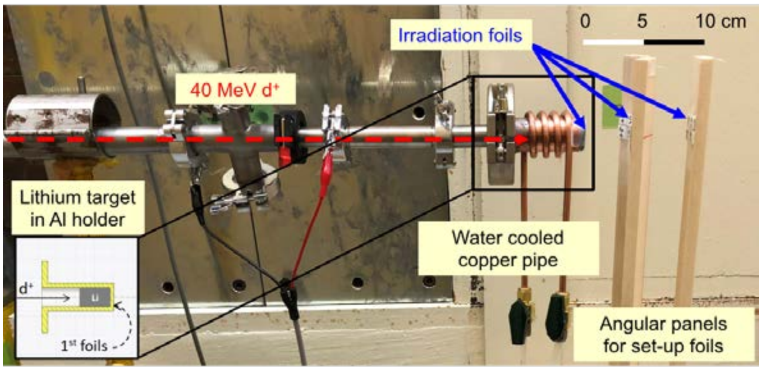

Figure 1. A photograph of the experimental setup.

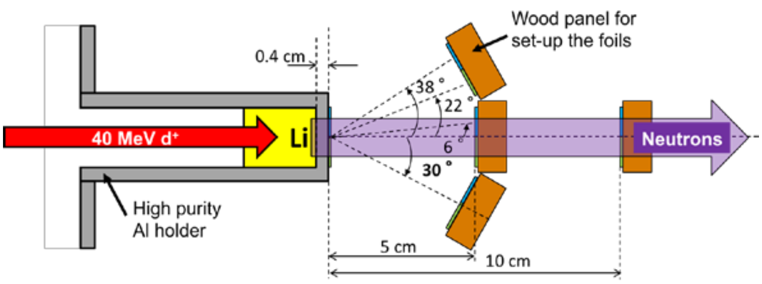

Figure 2. Cross sectional view of the experimental setup and irradiation foils position.

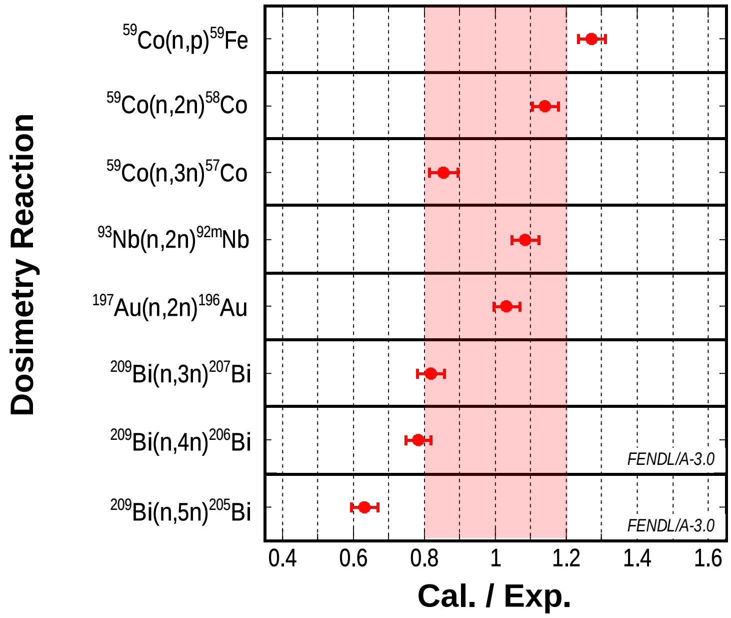

Figure 3. Cal./Exp. on the reaction rates of all reactions at 5 cm distance from the Li target holder.

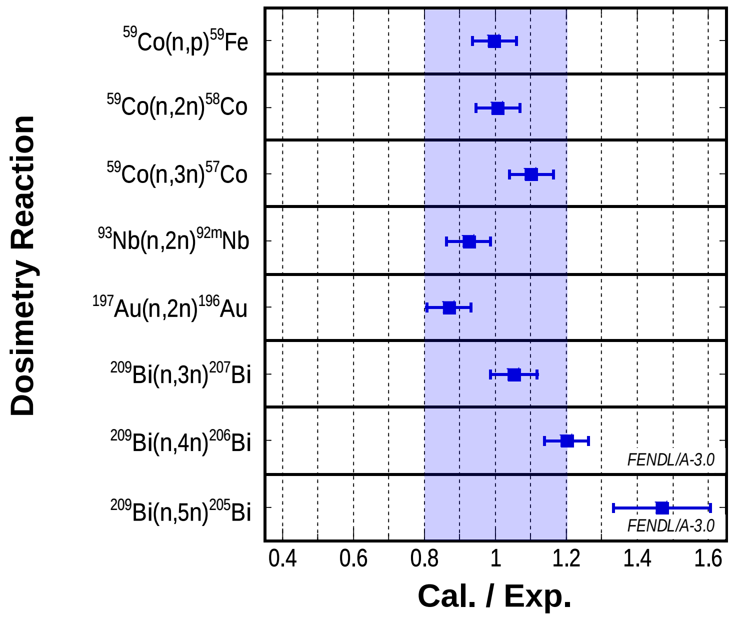

Figure 4. Cal./Exp. on the reaction rates of all reactions at 38° angle between the beam line and the foils.