Measurements of activation cross sections producing short-lived nuclei in the energy range of 2 - 3 MeV with pulsed neutron beam.

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To measure activation cross sections producing short-lived nuclei with half-lives less than 10 s, pulsed neutron beam were used. A HPGe detector was properly shielded from neutrons, because it was set on the irradiation room.

By using the d-D neutron source of the Fusion Neutronics Source in Japan Atomic Energy Research Institute. Four (n, n') reaction cross sections for ^{89}Y, ^{90}Zr, ^{137}Ba and ^{197}Au with half-lives between 0.8 s and 2.6 min were obtained in the energy range of 2 - 3 MeV. The cross section for ^{90}Zr (n, n') ^{90m}Zr reaction was obtained for the first time. Present results were compared with the evaluated data JENDL-3.3 and FENDL.

1. Introduction

In a D-T fusion reactor design, evaluated data libraries of neutron activation cross sections such as JENDL [1] are needed in the energy range up to about 20 MeV. They are used for estimation of the activities, gas productions, neutron damages and neutron dosimetry of the construction materials. The data of the libraries are evaluated on the basis of experimental data and theoretical calculations. Experimental data are also used to normalization of calculated excitation function, and improve the accuracy and reliability of the calculations.

When activation cross sections producing short-lived nuclei are measured, a pneumatic sample transport system which sends samples to the irradiating position and pulls them back to the measuring position about 2 - 3 s is usually used. Using this system, good statistics have been attained for the measurements of activation cross section with half-lives longer than several seconds. However, measurements of short-lived nuclei with half-lives less than several seconds are difficult to get enough statistics because radioisotopes decay out during the sample transfer.

The in-beam measurement is also useful for measurements of short-lived nuclei. However, there is a problem of high gamma-ray backgrounds, which would give some limitations to measurements of weak induced activities.

In this work, with pulsed neutron, neutron shielding is required for protection of a HPGe detector from d-D neutrons. Neutrons cause both the degradation of detector and the activation of detector. To irradiate samples with pulsed neutron beam, the operation of the accelerator was synchronized to activity measurements.

As test measurements, the activation cross sections of ^{89}Y (n, n') ^{89m}Y, ^{90}Zr (n, n') ^{90m}Zr, ^{137}Ba (n, n') ^{137m}Ba and ^{197}Au (n, n') ^{197m}Au reactions whose half-lives were between 0.8 s and 2.6 min were measured.

2. Experiment

2.1. Experimental procedure and apparatus

The d-D neutrons were produced via D (d, n) ^{3}He reaction by bombarding a deuterated titanium (Ti-D) target on a copper backing with a d^+ beam of 350 kV using the Fusion Neutronics Source (FNS) at Japan Atomic Energy Research Institute (JAERI). The durations of irradiation and measurement were chose to be the same, which is about two half-lives of the induced activity.

Figure 1 shows the experimental arrangement 1. We used the 0-degree beam line of the FNS to produce d-D neutrons. The sample was irradiated at the end of the collimator as a neutron shield, which was installed at angle of 80 degree with respect to the deuteron beam direction. The energy of emission neutron was 2.65 MeV. The diameter of collimator was 5 cm. The thickness of collimator was 200 cm. The distance between the neutron source and the sample was 390 cm. The induced activities were measured with the 10% HPGe detector. The distance between the sample and the detector was 5 cm.

The experimental arrangement 2 at the 80-degree beam line of the FNS is shown in Fig. 2. The sample was located at an angle of 0 degree with respect to the deuteron beam direction, the energy of emission neutron was 3.1 MeV. The distance between the neutron source and the sample was about 70 cm. The distance between the sample and detector was 2 cm. The HPGe detector was shielded against neutrons from the source by using polyethylene blocks with 60 cm thick and lead blocks 5 cm thick. Determination the optimum position of HPGe detector was done by the Monte-Carlo simulation code MCNP-4C [2]. The main cause of neutron leak was neutrons scattered from samples.

The neutron fluence rate was measured with use of the ^{115}In (n, n') ^{115m}In reaction ($T_{1/2}$ = 4.486 h), whose cross section data were taken from JENDL Dosimetry File 99 [3]. The measured fluence rates at sample position of each arrangement were 1 x 10^4 and 1 x 10^5 n/cm^2/s, respectively. The mean neutron energy at the irradiation position was determined by the ratio of induced activity by the ^{64}Zn (n, p) ^{64}Cu ($T_{1/2}$ = 12.701 h) to ^{115}In (n, n') ^{115m}In reactions.

2.2. Measurements of activation cross sections

Activation cross sections were measured by the activation method. All cross section values were determined by referring to the standard reaction cross section of ^{115}In (n, n') ^{115m}In. The samples were set on the irradiating position together with the indium foil as a monitor of neutron fluence rate. The indium foils were set behind the sample. The samples were 20 mm x 20 mm and 0.05 - 2 mm in thickness. The weights of samples were 0.4 - 10 g. In Table 1, the chemical form, the isotopic abundance and the weight of samples are listed.

Gamma rays emitted from the irradiated samples were measured with the HPGe detector. Gamma-ray spectra of ^{90}Zr (n, n') ^{90m}Zr reaction obtained by pulsed and continuous neutron beam are shown in Fig. 3-(a) and (b), respectively. The 2319 keV gamma-ray peak of interest is clearly seen in Fig. 3-(a). On the other hand, the gamma-ray peak of 2319 keV is not clearly observed owing to high room backgrounds as shown in Fig. 3-(b). The gamma rays emitted from indium and zinc were measured with a 115% HPGe detector after neutron irradiation.

2.3. Decay data

In Table 2, the decay data of half-lives, γ-ray energies and γ-ray emission probabilities are listed together with the measured reactions and the Q-values.

3. Results

The cross section data of four (n, n') reactions for ^{89}Y (neutron energy: E_n = 3.1 MeV), ^{90}Zr (E_n = 3.1 MeV), ^{137}Ba (E_n = 2.65 MeV) and ^{197}Au (E_n = 2.65, 3.1 MeV) were obtained. The present cross section values are shown in Fig. 4 together with the previous data measured with a pneumatic sample transport system, and the evaluated data in JENDL-3.3 and FENDL/A-2.0 [5]. These cross sections are in agreement with the previous data within the experimental uncertainties. The evaluated data for ^{137}Ba are overestimated. The data for ^{90}Zr in FENDL/A-2.0 are underestimated. Re-evaluations for those reactions are strongly recommended.

4. Conclusion

The method for measurement of activation cross sections with pulsed neutron beam is useful for producing nuclei with half-lives less than several seconds. In this method, activation cross sections down to about 300 mb could be measured.

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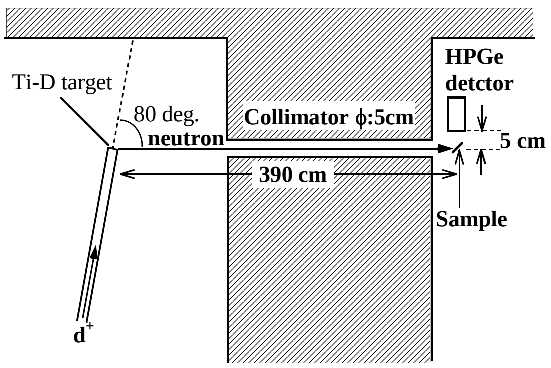

Fig. 1. The schematic view of the present experimental arrangement 1.

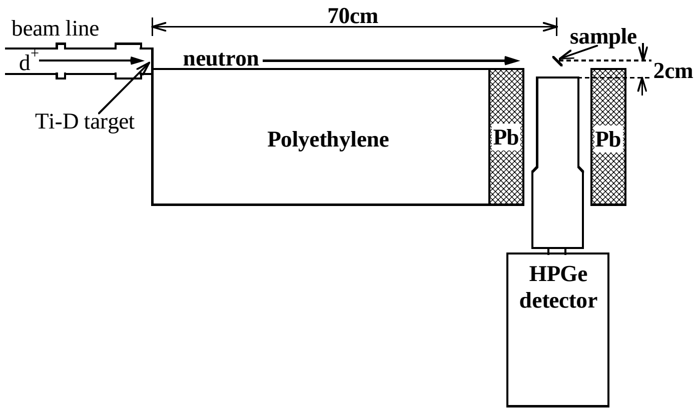

Fig. 2. The schematic view of the present experimental arrangement 2.

Table 1. Chemical form, weight and abundance of the samples

Target nuclei (isotopic composition)	Chemical form	Arrangement 1 Weight [g]	Arrangement 2 Weight [g]	Abundance [%]
^{89}Y (natural)	Y	3.2	1.1	100
^{90}Zr (natural)	Zr	10	2.5	51.45
^{137}Ba (enriched)	$BaCO_3$	0.4	---	64.04(137), 0.02(130), 0.02(132), 0.06(134), 0.23(135), 1.55(136), 34.12(138)
^{197}Au (natural)	Au	3.2	0.4	100

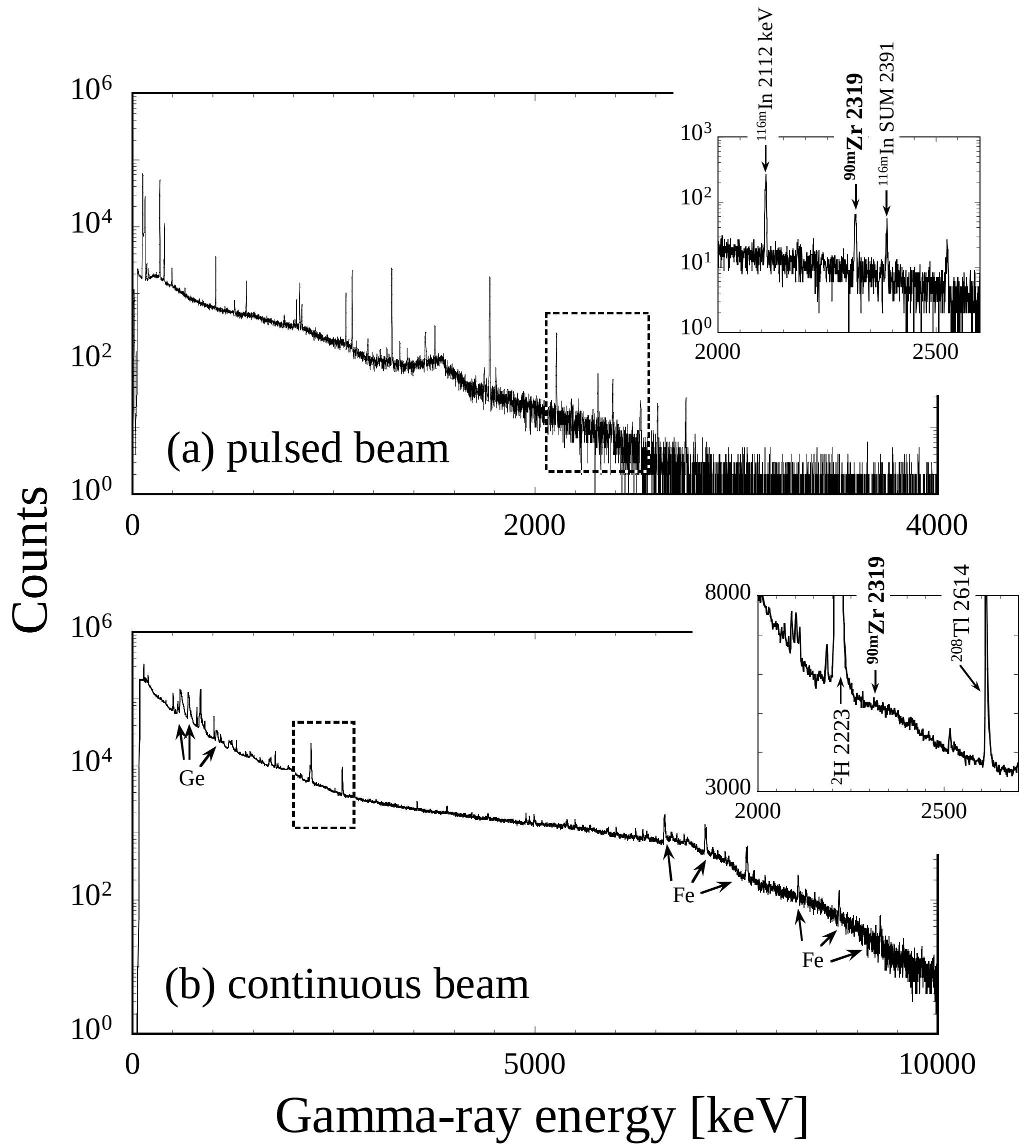

Fig. 3. Gamma-ray spectra of ^{90}Zr (n, n') ^{90m}Zr reaction measured with the pulsed neutron beam (a) and the continuous neutron beam (b).

Table 2. Measured reactions and associated decay data[a)]

Reaction	Half-life	γ-ray energy [keV]	γ-ray emission probability [%]	Q-value [keV]
^{89}Y (n, n') ^{89m}Y	16.06$_{4}$ s	909.15$_{7}$	99.14$_{10}$	909.15
^{90}Zr (n, n') ^{90m}Zr	809.2$_{20}$ ms	2318.900$_{5}$	84$_{1}$	2319.000
^{137}Ba (n, n') ^{137m}Ba	2.552$_{1}$ min	661.660$_{3}$	90.1$_{1}$	661.660
^{197}Au (n, n') ^{197m}Au	7.8$_{1}$ s	279.11$_{6}$	73$_{11}$	409.15
^{115}In (n, n') ^{115m}In[b)]	4.486$_{4}$ h	336.258$_{18}$	45.8$_{22}$	336.258

a) Taken from ref. 4.

b) Standard reaction used for neutron fluence rate monitor.

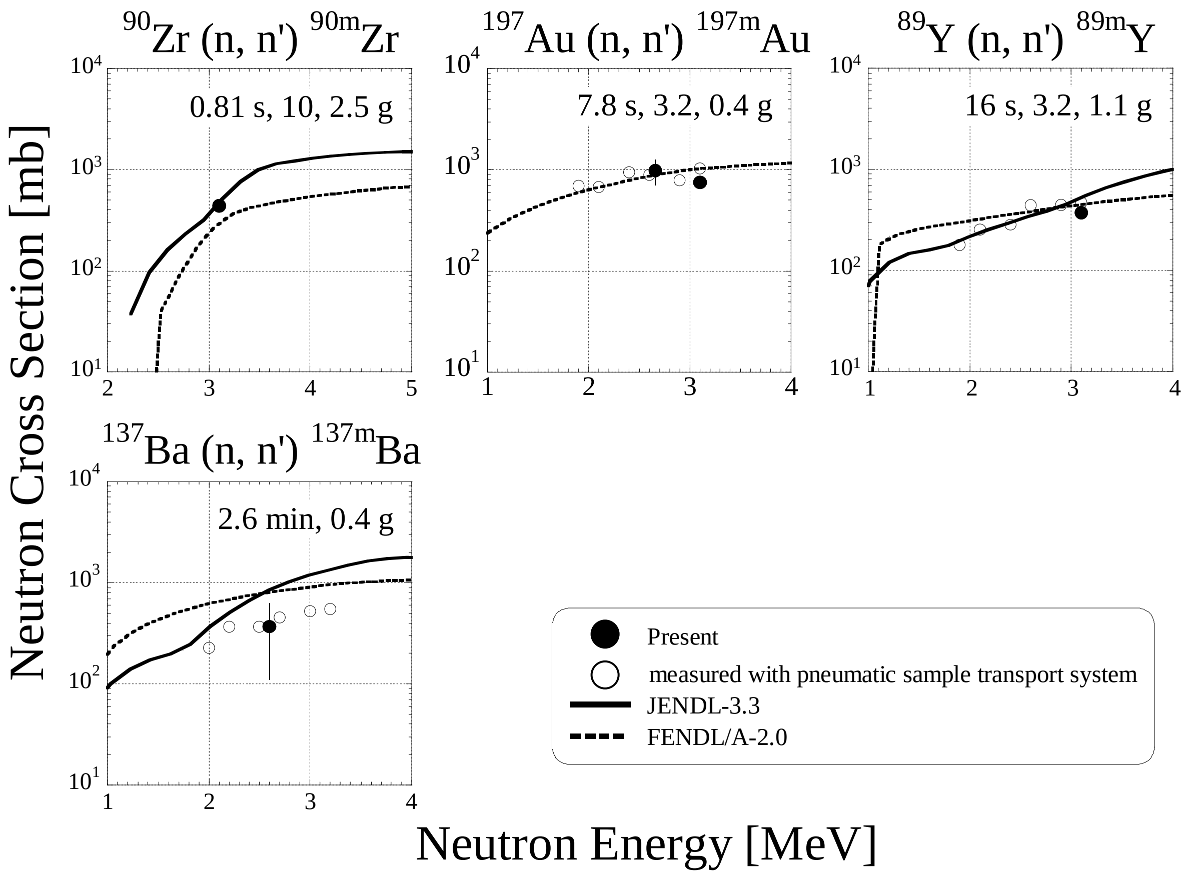

Fig. 4. The experimental cross section data for (n, n') reaction compared with the previous experimental data and the evaluated data in JENDL-3.3 and FENDL/A-2.0.