# Fission Cross Section Measurement for Am-242m with TOF Methods in Low Energy Region

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The neutron-induced fission cross section for Am-242m was measured with time-of-flight(TOF) method from 0.003 eV to 30 eV. We already measured the cross section using Kyoto University lead slowing-down spectrometer(KULS) from 0.1 eV to 10 keV and using the standard thermal neutron field ($D_2O$ facility) at 0.025 eV. The present result was compared with both of them. Although the JENDL-3.2 and ENDF/B-VI were slightly higher in the energy region lower than ∼1 eV, the present result agreed with the KULS result and the $D_2O$ result within their experimental error.

## 1 Introduction

Americium(Am) isotopes are burdensome minor actinides which are abundantly produced in power reactors. The nuclear data for them are of grate importance for system design of spent fuel reprocessing and its transmutation from the standpoint of the disposal of radioactive waste [1]-[5]. The cross section for Am-242m is also notable as well as Am-241 and Am-243 because of its large fission cross section in lower energy region (thermal neutron-induced fission cross section for Am-242m is about ten times larger than uranium-235). But there exist large discrepancies among the evaluated fission cross sections for Am-242m in the JENDL-3.2 and the ENDF/B-VI data file especially at resonance energies. Recently, the authors measured the fission cross section for Am-242m using Kyoto University lead slowing-down spectrometer (KULS[6]) from 0.1 eV to 10 keV[7] and using the standard thermal neutron field ($D_2O$ facility) at 0.025eV[8]. In fig.1, the results of them and the evaluated data (the ENDF/B-VI and the JENDL-3.2) were compared each other. The evaluated data were broadened with the energy resolution of the KULS. In this figure, it was difficult to discuss whether the result using the $D_2O$ facility was consistent with that obtained using the KULS since the KULS result was broadened. We took place the

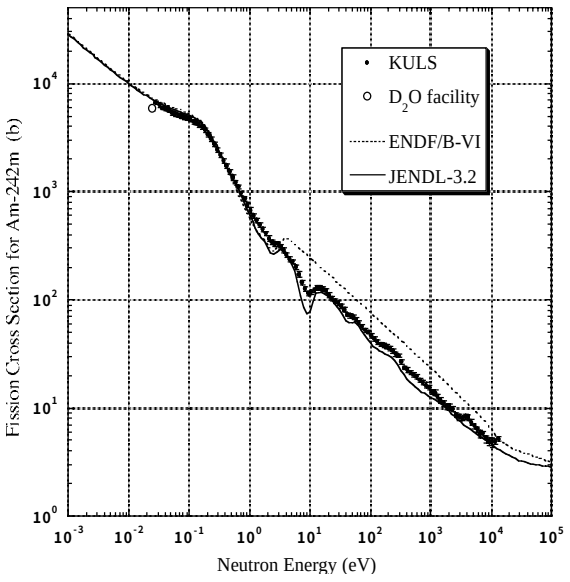


Fig. 1: The result measured with the KULS and the $D_2O$ facility was compared with the evaluated data broadened with the energy resolution of the KULS.

cross section measurement for Am-242m with TOF method for the two purposes. One was discussion about the consistency between the KULS result and the $D_2O$ facility one. Another was to measure the cross section in further lower energy region.

## 2 Experimental Methods

### 2.1 The Am-242m and U-235 samples

The Am-242m deposit was purchased from Chemotrade GMBH, and the Am-242m was electrodeposited (radioactive area of 20 mm in diameter) on the stainless steel disk (28 mm in diameter and 0.2 mm in thickness). The purity of the Am-242m was 85.25 %, and the major impurities were 14.42 % for Am-241 and 0.53 % for Am-243. The number of Am-242m atoms was determined by alpha and gamma-ray spectroscopies. As a result of both analyses, the number of Am-242m atoms was determined to be $(2.04 \pm 0.04) \times 10^{16}$.

The highly enriched uranium oxide (99.91 % of U-235) was gotten from ORNL. The uranium was also electrodeposited on the stainless steel disk. The U-235 sample was used to monitor the neutron flux in this study as the well-known reference cross section of the $^{235}$U(n,f) reaction. As well as the Am-242m sample, the number of U-235 atoms was determined to be $(3.28 \pm 0.04) \times 10^{17}$.

### 2.2 Back-to-back Type Double Fission Chamber

The fission chamber was composed of two identical parallel plate-type ionization chambers, as shown in fig.2. The back sides of the sample deposit (Am-242m) and the reference one (U-235) were face each other. This chamber was originally designed for in-core fission ratio measurement [9]. This chamber was made of aluminum and filled with a mixed gas of 97 % Ar and 3 % of $N_2$ at pressure of 1 atm. Fission pulses were clearly discriminated from background ones caused by the alpha-rays since the electrodeposited layers of Am and U are enough thin not to reduce the energy of fission fragments.

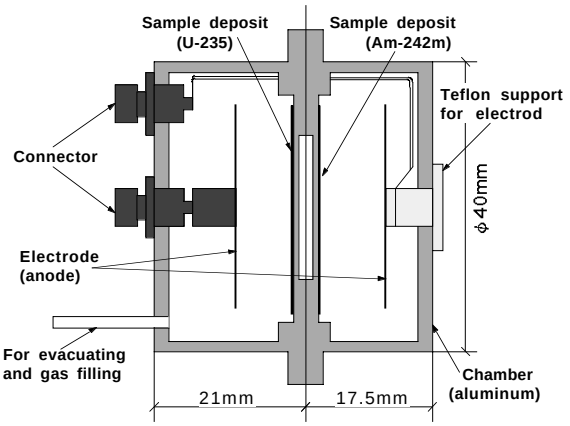


Fig. 2: Cross Sectional view of the back-to-back type doubele fission chamber.

### 2.3 The $BF_3$ Counter

The $^{10}$B(n, $\alpha$) reaction is well known to be one of the standard cross section and is often applied to cross section measurement as a reference. Instead of $^{235}$U(n, f) reaction, the $^{10}$B(n, $\alpha$) reaction was applied as a reference using a $BF_3$ counter in resonance region in order to avoid resonance interference between Am-242m and U-235 fission cross sections. The $BF_3$ counter was of a cylindrical type, 50 mm in effective length, 12 mm in diameter, 1 atm in gas pressure and high-voltage bias was 1100 V.

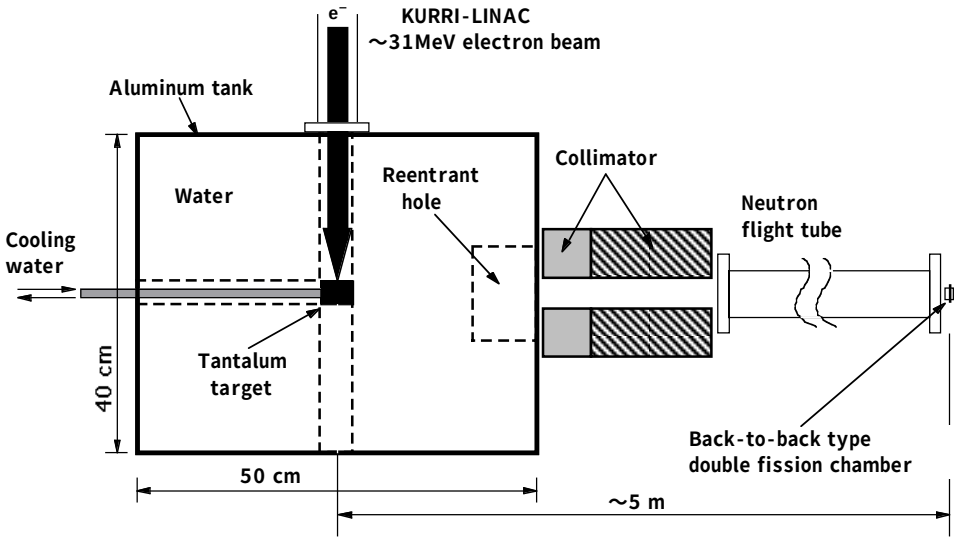


Fig. 3: The schematic view of the experimental arrangement for the present measurement.

### 2.4 Experimental Arrangement

The measurement with TOF method was made using the 46 MeV electron linac at Kyoto University Research Reactor Institute. The schematic view of experimental arrangement is shown in fig.3. The pulsed neutron produced at the water-cooled tantalum(Ta) target as a result of electron beam irradiation were taken out from the reentrant hole (19 cm in diameter) in the center of the water tank (aluminum, $50\times40\times50$ cm$^3$). The sample deposit(Am-242m) and the reference one (U-235) was set in the back-to-back type double fission chamber, and the chamber was placed at approximately 5 m from the Ta target. The typical operating conditions of the linac during this measurement were as follows: pulse repetition of 80 Hz, pulse width of 22 ns, electron average current of $\sim 75\mu$s, and the energy of $\sim 31$ MeV.

### 2.5 Energy Calibration

In general, the energy of neutron could be determined from flight time and path of the neutron. The reason why we took place energy calibration with the resonance filters was that the neutron source region was unnegligibly wide comparing with the flight path. The characteristics of the resonance filters are shown in tab.1. During the energy calibration, neutrons reached the $BF_3$ counter trough the resonance filters. The depressions corresponding to resonance energy of the filter materials were found in the time spectrum. The effective flight path was determined to be $5.01 \pm 0.02$m as a result of fitting with least squares method for the dependency between resonance energy and the flight time (fig.4).

Table 1: The characteristics of the resonance filters used for energy calibration.

| Material | Energy (eV) | Thickness (mm) | Form |
|---|---|---|---|
| Samarium | 0.87<br>8.05 | 0.5 | Matel Plate |
| Silver | 5.19<br>16.3 | 0.5 | Matel Plate |
| Indium | 1.46 | 0.2 | Metal plate |

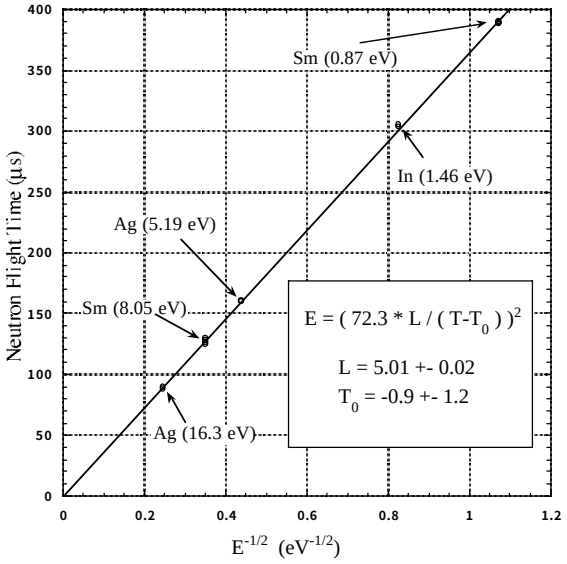


Fig. 4: Dependency between neutron flight time and its energy.

### 2.6 Data taking and Fission Ratio Measurement

Two identical electronic circuits were employed for the Am-242m and U-235 chambers. Through the amplifiers and discriminators, signals from the chambers were fed into the 4096-channel time-analyzer with 2 $\mu$s/channel, which was initiated by the linac electron burst, and the time-of-flight data of fission counts were stored for each measurement of $\sim$5-hour duration in a data acquisition system.

The fission cross section for Am-242m ($\sigma_{\mathrm{Am}}(\mathrm{E})$) was obtaind by eq.1.

$$\sigma_{\mathrm{Am}}(\mathrm{E}) = \begin{cases} \dfrac{\mathrm{C_{Am}(E)}}{\mathrm{C_U}} \dfrac{\mathrm{N_U}}{\mathrm{N_{Am}}} \sigma_{\mathrm{U}}(\mathrm{E}) & (0.003 \sim 0.2\,\mathrm{eV}) \\ \dfrac{\mathrm{C_{Am}(E)}}{\mathrm{C_B}} \mathrm{N_r} \sigma_{\mathrm{B}}(\mathrm{E}) & (0.2 \sim 35\,\mathrm{eV}) \end{cases} \tag{1}$$

where

| | |
|---|---|
| $\mathrm{C_{Am}(E)}, \mathrm{C_U(E)}$ | : fission counts of Am-242m and U-235 for neutron energy E, |
| $\mathrm{C_B(E)}$ | : number of $^{10}$B(n,$\alpha$) reactions for neutron energy E, |
| $\mathrm{N_{Am}}, \mathrm{N_U}$ | : number of Am-242m and U-235 atoms in the deposits, |
| $\sigma_{\mathrm{U}}(\mathrm{E}), \sigma_{\mathrm{B}}(\mathrm{E})$ | : the $^{235}$U(n,f) and $^{10}$B(n,$\alpha$) cross section cited from the ENDF/B-VI, |
| $\mathrm{N_r}$ | : normalizing factor. |

The absolute value of the fission cross section for Am-242m was measured relative to that for U-235 from 0.003 eV to 1 eV making use of the back-to-back type double fission chamber. In order to avoid the resonance interference between Am-242m and U-235, the relative fission cross section measurement was made using a $BF_3$ counter as a good $1/v$ detector instead of the U-235 fission chamber from 0.2 eV to 10 eV. This relative cross section was normalized to the absolute value measured relative to U-235 between 0.2 eV and 1 eV.

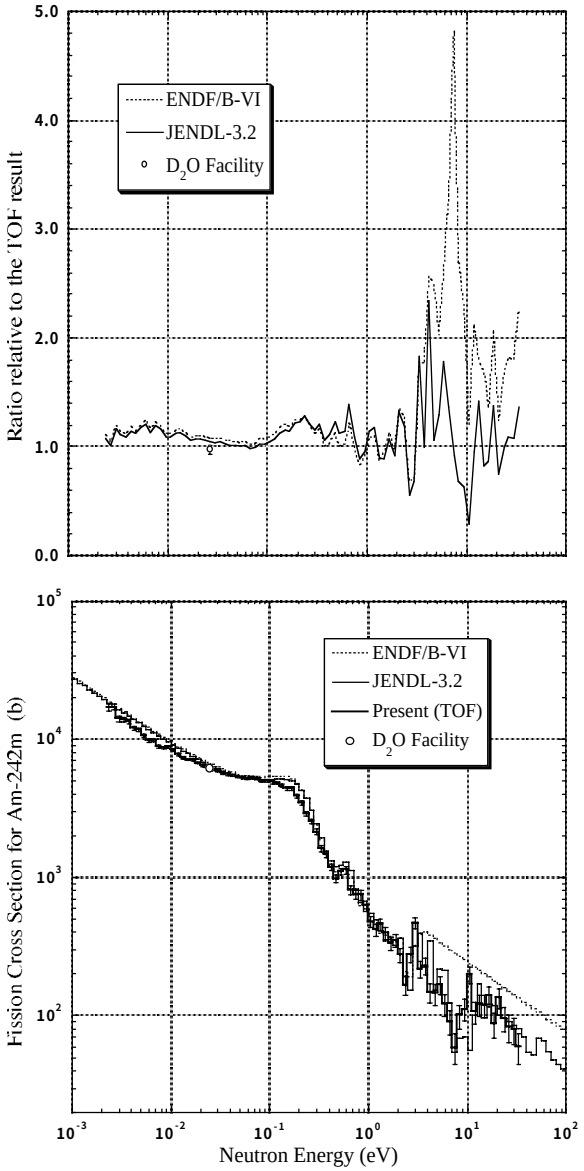


Fig. 5: Comparison between the present result and the value obtained with the $D_2O$ facility and the evaluated data.

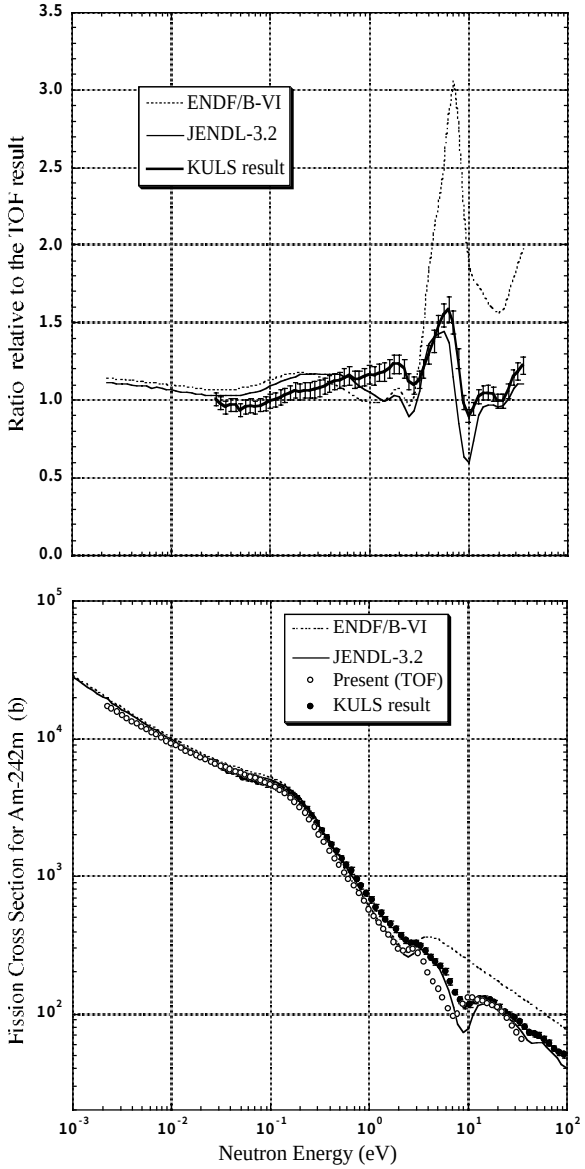


Fig. 6: Comparison between the present result and evaluated data and the KULS result. The present one and evaluated data were broadened for comparison.

## 3 Results and Discussion

The present result, the $D_2O$ result and the evaluated data of the JENDL-3.2 and the ENDF/B-VI were compared in fig.5. Although the present result and the $D_2O$ result agree in their experimental error at 0.025 eV, the JENDL-3.2 and the ENDF/B-VI were slightly larger than our results. In higher energy region ($>\sim$3 eV), the ENDF/B-VI data was much higher than the present result and the JENDL-3.2. As shown in fig.6, the result with the TOF method and that with the KULS were compared with the evaluated data. For the comparison, the TOF result and the evaluated data were broadened with the energy resolution of the KULS. Although the present result was systematically differ from the KULS result and evaluated data from 5 to 7 eV, good agreement could be seen between the TOF result and the KULS result in the energy region lower than $\sim$0.2 eV. The reason for the systematical difference might be that the statistical accuracy during the present measurement was not enough.

## 4 Conclusion

(1) 0.003$\sim$3 eV

The thermal neutron-induced fission cross section obtained with the $D_2O$ facility is consistent with the result measured using the KULS since both results show good agreement with the result with the TOF method. But the JENDL-3.2 and the ENDF/B-VI data are slightly higher than our results in this energy region.

(2) 3$\sim$ 35 eV

The KULS data and the evaluated data are systematically higher than the present result in the energy region from 5 to 7 eV. But the ENDF/B-VI data is apparently larger than not only the present result but also the KULS result and the JENDL-3.2 data.

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