Present Status of Minor Actinide Nuclear Data

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Present status of neutron-induced fission and capture cross sections of Np to Cm isotopes was investigated. It is emphasized in this talk that new experimental data are needed in order to improve the current evaluated nuclear data libraries.

1. Introduction

Nuclear data of minor actinides (MA) are important for estimation of amount of MA in reactors, and for study of transmutation technology of MA. From the benchmark tests [1] with post irradiation experiments indicated that the current evaluated data of JENDL-3.3, ENDF/B-VI and JEFF-3.0 could not predict well the amounts of MA in the reactors, in particular for Am and Cm isotopes. A report [2] from a group studying ADS (Accelerator Driven System) for transmutation of MA showed large discrepancies among k-eff values calculated from JENDL-3.3, ENDF/B-VI and JEF-2.2. In order to improve the current evaluated data, we have to know well the present status of MA data.

In the present paper, the status of thermal cross sections and the cross sections above 1 keV are summarized mainly for Np, Am and Cm isotopes. The data of number of neutrons per fission are also shown.

2. Thermal cross sections

The most serious problem of thermal neutron cross sections is the ^{241}Am capture cross section. Several experimental data exit for this cross section. However their recent experimental data are larger than the thermal cross sections recommended in the current evaluated data libraries. Table 1 shows the comparison of recent experimental data with the evaluated data. JENDL-3.3 gives the largest cross section of 640 barns, while it is smaller than the experiments.

The total cross section of ^{241}Am was measured before 1976. Those experimental data are well reproduced by the current evaluated data. The total cross section at 0.0253 eV is about 650 barns at the largest. The evaluation for JENDL-3.3 was based on mainly the total cross sections reported in 1970's, and gave the large thermal cross section of 654 barns. However the recent experimental data for the capture cross section are larger than this total cross section.

Katoh et al. [3] reported the thermal capture cross section of ^{237}Np recently. Their data of 141.7±5.4 barns is smaller than the evaluated data (162 b of JENDL-3.3, and 181 b of ENDF/B-VI and JEFF-3.0) and experimental data of Kobayashi et al. [4] (158±3 b) and Weston et al. [5] (180±6 b).

Table 2 shows the measurements reported after 1990 for the thermal cross sections, resonance integrals and resolved resonance parameters. It is noticeable that the measurements for Cm isotopes are quite scarce, and those for other isotopes are not many enough too. In order to improve the evaluated data below the resonance region, we strongly need new experimental data for the MA.

Table 3 gives very rough status of the data in the thermal energy region. "○" means that many experimental data exit and the evaluated data are in good agreement with them, "△" that not enough because of discrepancies among experimental data themselves and evaluated data, and "×" that no experimental data are available, therefore the reliability of the evaluated data is quite low. For many isotopes, the current experimental data are not enough and too old.

3. Lead Slowing Down Spectrometer

Cross-section measurements with lead slowing down spectrometers have been performed using KULS at Kyoto University and RINS at Rensselaer Polytechnic Institute. These experimental facilities have very strong neutron intensities. Therefore average cross sections can be measured with very good statistical accuracies. Those data can be used to test the resonance parameters given in the evaluated data libraries.

Figure 1 shows the ^{243}Am fission cross sections as an example. It is seen that the data of JEFF-3.0 are too small, and the ENDF/B-VI has a little problem above 10 eV. From the comparison of JENDL-3.3 and those experimental data, discrepancies have been found for ^{237}Np fission, ^{237}Np capture, ^{244}Cm fission and ^{246}Cm fission cross sections [6].

4. Isomeric Ratio of ^{241}Am neutron capture cross section

The isomeric ratio (IR) of ^{241}Am neutron capture is one of important nuclear data for estimation of nuclear production above ^{242}Am. Experimental data exist in the thermal region, which are about 0.9. However no good experimental data are available in the higher energy region.

The data of JENDL-3.3 was calculated with the statistical model, and normalized to the upper limit of error bar of the data measured by Wisshak et al. [7] at 29 keV. However it has been pointed out that the IR to ^{242g}Am given in JENDL-3.3 is too small above the thermal region. Kawano et al. [8] evaluated this quantity recently on the basis of the statistical model calculation and integral data measured at Los Alamos, and obtained larger values than JENDL-3.3.

Figure 2 shows IR to the ground state of ^{242}Am. The data of 0.84 at 300 keV is an integral data measured by Dovbenko et al. [9] using BR-5 reactor. The data of Kawano et al. gives IR of about 0.85 in a typical fast reactor spectrum [10]. The data of Kawano et al. are the most reliable at the present among the current evaluated data.

5. Cross Sections above 1 keV

Fission cross sections above 1 keV have relatively many experimental data. Figure 3 shows the fission cross section of ^{241}Am. The experimental data reported after 1980 in the figure are consistent with each other and the data of JENDL-3.3 are in good agreement with them.

The fission cross section of ^{243}Am are shown in Fig. 4. The experimental data are separated into two groups in the MeV region. The reason of these discrepancies is not clear. JENDL-3.3 follows the data in the lower group.

The data of ^{242}Cm are illustrated in Fig. 5. The data of ENDF/B-VI is largely underestimated. JENDL-3.3 and JEFF-3.0 reproduce well experimental data.

In the case of ^{243}Cm fission cross section, the experimental data are discrepant with each other as shown in Fig. 6. JENDL-3.3 is based on the most recent data of Fursov et al. [11]

In Figures 7 and 8, examples of capture cross sections are given. The ^{241}Am capture cross section in Fig. 7 has experimental data up to several hundred keV. At the higher energies, evaluated data are largely discrepant. For the ^{243}Cm capture cross section, no experimental data are available in the energy range above 1 keV. We therefore cannot confirm the reliability of the current evaluated data.

Table 4 shows the statistics of recent measurements of fission and capture cross sections reported after 1990. The fission cross sections have been often reported. On the contrary no data have been reported for the capture cross sections after 1990. The present status of the cross sections is summarized in Table 5. The situation of the fission cross section is better than the capture cross section whose experimental data are too old or not available.

6. Number of Neutrons per Fission

An example of the total number of neutrons per fission (ν) is given in Fig. 9 where shown are the evaluated data of ν-total and experimental data of ν-prompt or ν-total for ^{241}Am. The evaluated data are discrepant from each other. JENDL-3.3 adopted a fitting curve reported by Khokhlov et al. [12] However their measured data points stored in EXFOR are not reproduced with the fitting curve as

shown in the figure. Since these data points inconsistent with Ref. [12] were not available at the time of evaluation, JENDL-3.3 dose not reproduce them.

In the case of ^{243}Cm in Fig. 10, the experimental data exist only at the thermal energy. The evaluated data reproduce those experimental data, while the energy dependences are different. For many nuclides the situation is the similar to ^{243}Cm.

7. Conclusions

It was found that the current experimental data are not enough to deduce the accurate evaluated data for MA. New measurements are strongly expected for the ^{241}Am thermal cross sections, capture cross sections above the resolved resonance region for Cm isotopes, and so on.

References

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Table 1 ^{241}Am thermal capture cross sections

Reference	cross section (barns)
Mughabghab [13]	587±12
Shinohara et al. [14]	854±58
Fioni et al. [15]	696±48
Maidana et al.[16]	(660)*
JENDL-3.3	640
ENDF/B-VI	619
JEFF-3.3	616

* Maidana et al. [16] reported the cross section to ^{242}Am ground state (602±9 barns). The total capture was estimated by assuming the isomeric ratio of 0.91.

Table 2 Thermal cross sections, resonance integrals and resonance parameters reported after 1990

Nuclide	thermal cross section	Res. Integ.	Res. Parms.
Np236	σf(96)	RIf(96)	Res(96)
Np237	σc(94,03)	RIc(94,99,03)	Res(94)
Np238	σc(03), σf(95,96,97)	RIf(95)	Res(96)
Pu236	σf(90)	RIf(90)	Res(90)
Pu238	σf(90)	RIf(90)	
Am241	σc(97,01,01), σf(96)	RIc(97,01)	
Am242g	σc(01)		
Am242m	σf(01)		
Am243	σc(98), σf(99)		
Cm247	σf(94)	RIf(94)	Res(94)

Table 3 Present status of thermal cross sections

Nuclide	fission	capture	comments
Np237	△[1]	△[2]	1) not agree with KULS, 2) large discrepancies
Pu238	△	△[1]	1) old experiments.
Pu242	×	○	
Am241	○	△[1]	1) large discrepancies
Am242m	△[1]	×	1) large discrepancies
Am243	△[1]	△[2]	1) large discrepancies, 2) old experiments
Cm242	×	△[1]	1) old experiments (absorption)
Cm243	△	△	old experiments
Cm244	△	△	old experiments
Cm245	○	△	old experiments
Cm246	△	△	old experiments

Table 4 Fission and capture cross sections reported after 1990

Np236	σf(96,97)	Am242m	σf(91,97,97)
Np237	σf(many)	Am243	σf(99,99)
Np238	σf(96)	Cm243	σf(90,91,97)
Pu236	σf(90,97)	Cm244	σf(91,97)
Pu238	σf(97)	Cm245	σf(91,91,97,97)
Pu242	σf(98)	Cm246	σf(91,97,97)
Pu244	σf(98)	Cm247	σf(91,91,94,97,97)
Am241	σf(99)	Cm248	σf(97)

Table 5 Present status of fission and capture cross sections

Nuclide	fission	capture	comments
Np237	△[1]	△[2]	1) discrepancies: E<100keV. 2) not enough: E> 100keV
Pu238	△[1]	△[2]	1) discrepancies. 2) old exp, no data: E>100keV
Pu242	○[1]	△[2]	1) no exp.: E<100keV. 2) no exp.: E>100keV
Am241	○	△[1]	1) no experiments: E>100keV
Am242m	△[1]	×	1) large discrepancies
Am243	△[1]	△	1) large discrepancies
Cm242	△[1]	×	1) no experiments in the MeV region
Cm243	△[1]	×	1) no experiments: E<100keV
Cm244	△[1]	×[2]	1) discrepancies. 2) no exp.: E>10 keV
Cm245	○	×	
Cm246	○	×	

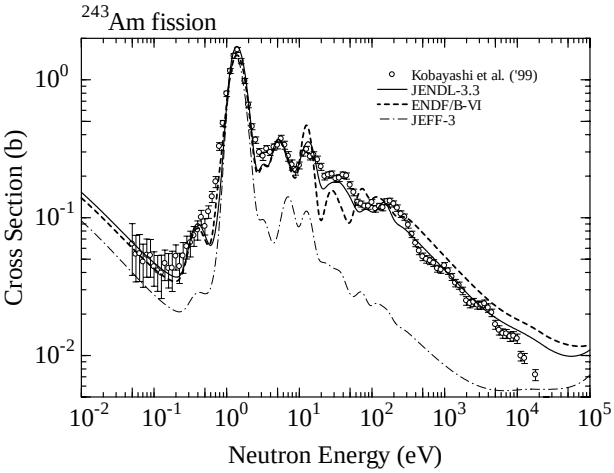

Fig. 1 ^{243}Am fission cross section measured At KULS

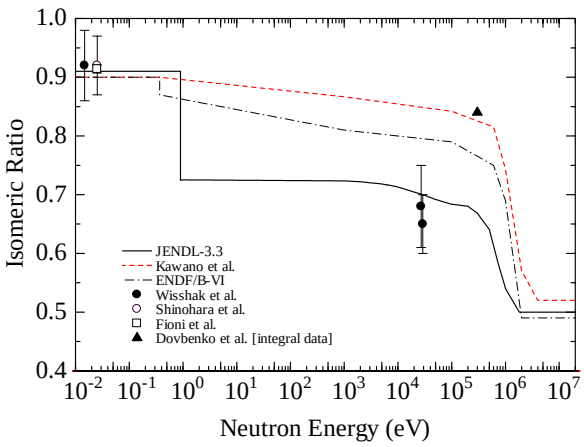

Fig.2 Isomeric ratio ^{241}Am neutron capture

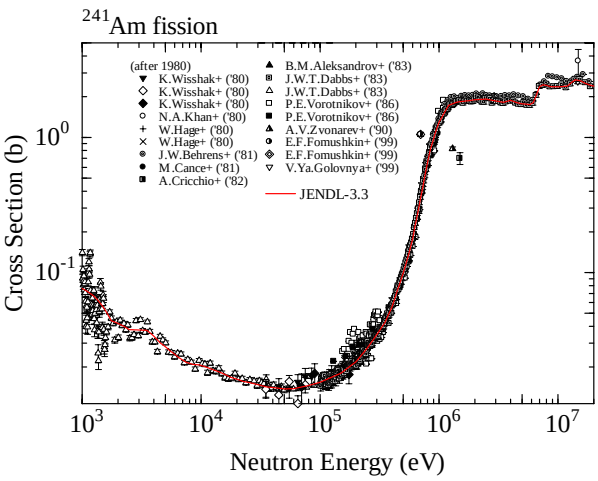

Fig.3 ^{241}Am fission cross section

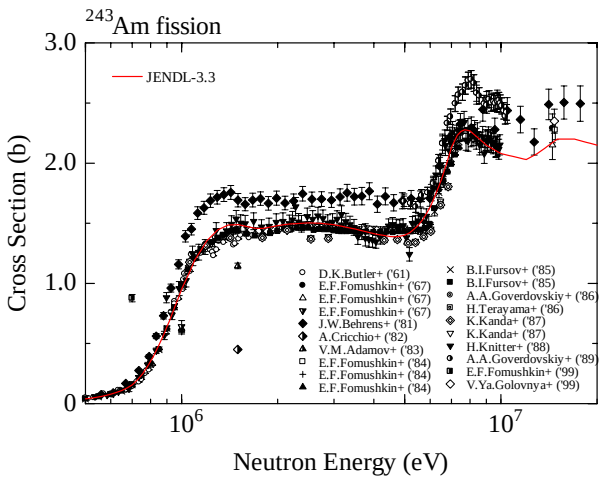

Fig.4 ^{243}Am fission cross section

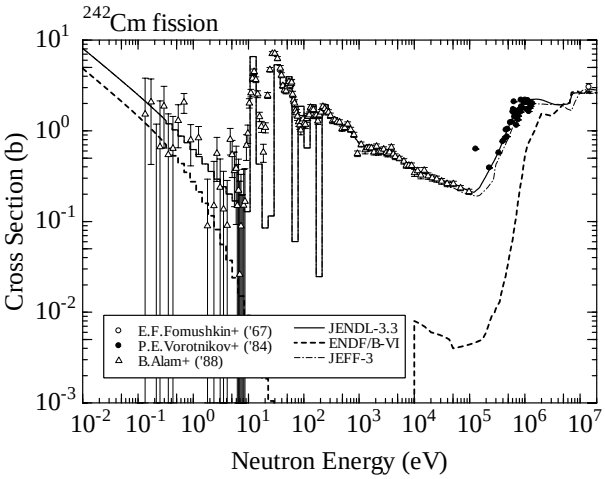

Fig. 5 ^{242}Cm fission cross section

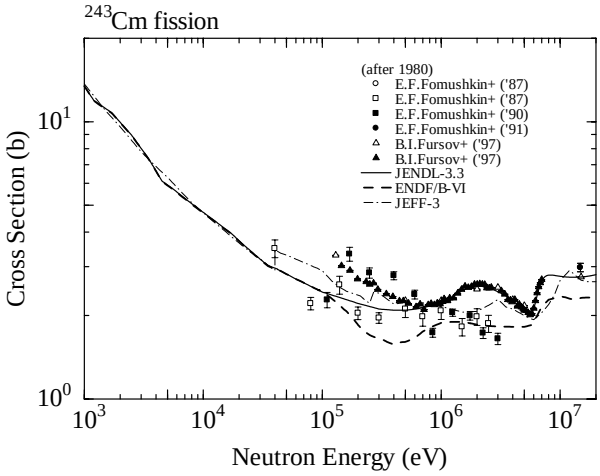

Fig. 6 ^{243}Cm fission cross section

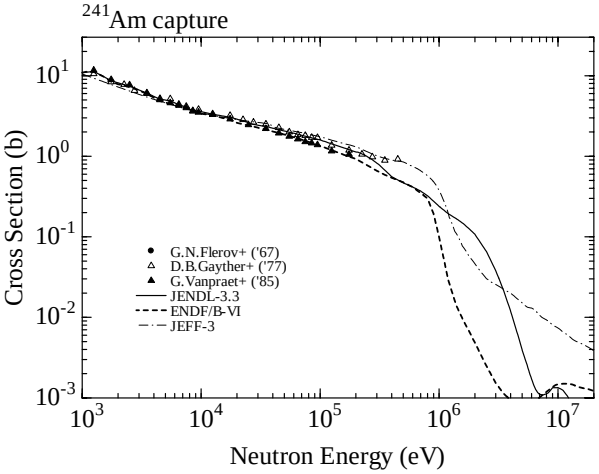

Fig. 7 ^{241}Am neutron capture cross section

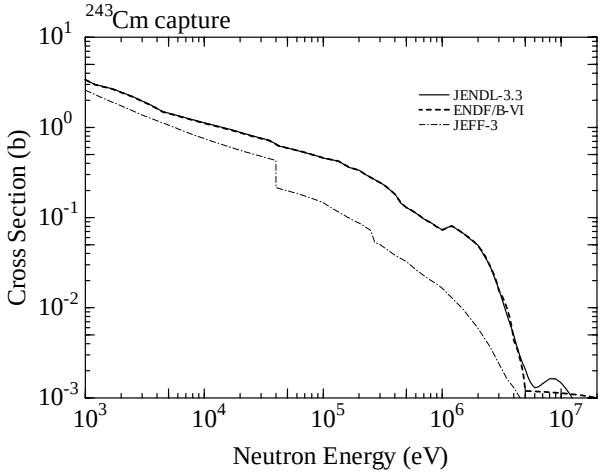

Fig. 8 ^{243}Cm neutron capture cross section

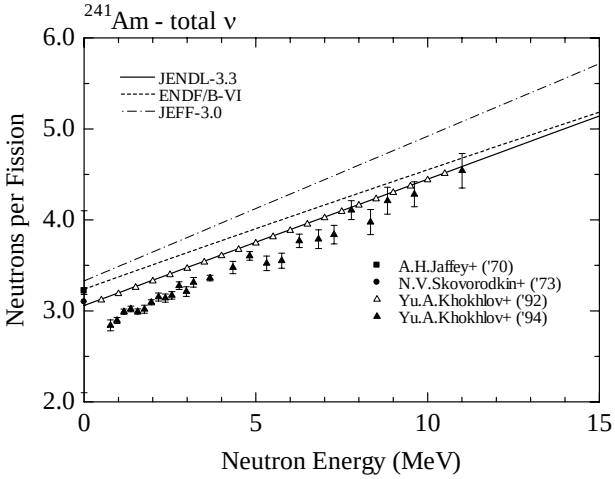

Fig. 9 ^{241}Am neutrons per fission

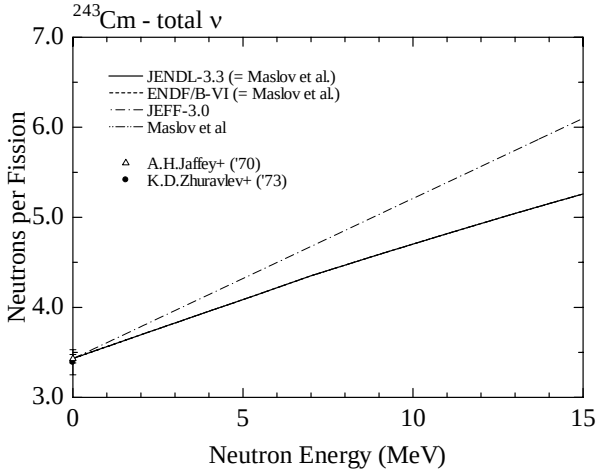

Fig. 10 ^{243}Cm neutrons per fission