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EVALUATION OF TRANSPLUTONIUM NUCLEAR DATA

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Abstract: Evaluation of nuclear data for transplutonium nuclides has been performed in the energy range from 0.01 meV to 20 MeV. The quantities evaluated are cross sections of total, elastic and inelastic scattering, fission, (n,2n), (n,3n) and (n,4n) reactions. The angular distributions and energy distributions of emitted neutrons and the number of neutrons per fission were also given for each nuclide. In a low energy range, resolved and unresolved resonance parameters were given to reproduce the cross sections. In a high energy region, theoretical calculations with optical, statistical and evaporation models were used except for the fission cross section which was determined from the experimental data or systematic trend. So far, evaluated data have been given for 20 nuclides; Am-241, 242, 242m, 243, 244, 244m, Cm-242, 243, 244, 245, 246, 247, 248, 249, Bk-249, 250 and Cf-249, 250, 251, 252. The evaluated results were compiled in the ENDF-5 format and will be stored in JENDL-3.

(Evaluation, Nuclear Data, Americium, Curium, Berkelium, Californium, Resonances, Cross sections, Angular Distributions, Energy Distributions)

Introduction

Neutron nuclear data of transplutonium nuclides are important for nuclear fuel cycles of thermal and fast reactors.

In the Nuclear Data Center of Japan Atomic Energy Research Institute (JAERI), the evaluation work for the transplutonium isotopes has been continued since 1977 under contracts between Power Reactor and Nuclear Fuel Development Corporation (PNC) and JAERI. By the end of 1986, we have completed the evaluation for nuclides ranging from Am-241 to Cf-252. Recently, the data of Am isotopes were re-evaluated because new important experiments had been reported since our previous evaluation.

JENDL-2 /1/ contains the data for 8 nuclides from Am-241 to Cm-245, while all of the evaluated data for 20 nuclides will be stored in JENDL-3 which is the latest version of Japanese Evaluated Nuclear Data Library.

In the following sections, the method of the present evaluation is described. Since the evaluation of data for Cm, Bk and Cf isotopes were published elsewhere /2-10/, only the data of important Am isotopes are explained in this report.

Evaluation Method

General

The evaluation was made in the neutron energy range from 0.01 meV to 20 MeV. In a low energy region, resolved resonance parameters were given. The parameters were mainly taken from up-to-date experimental reports and slight modifications were made so as to reproduce measured thermal cross sections. In the case where no experimentally determined parameters existed, hypothetical resonances were generated on the basis of level density parameters and average resonance parameters estimated from optical model or thier systematics. For almost all nuclides, the multi-level Breit-Wigner formula was adopted.

The unresolved resonance parameters were evaluated up to 30 or 40 keV. These parameters were determined with ASREP /11/ so as to reproduce the fission and capture cross sections evaluated as follows.

The fission cross section was evaluated on the basis of experimental data. If experimental data were not available, it was estimated from systematic trend of the fission cross section. The estimated fission cross section was normalized around 3 MeV to the systematics obtained by Behrens and Howerton /12/ or by Lasijo /13/.

The (n,Xn) cross sections were calculated with simple evaporation model by considering that differences between compound nucleus formation cross section calculated with the optical model and fission cross section was the total neutron emission cross section.

The other cross sections were obtained with optical and statistical model code CASTHY /14/ which calculates the cross sections and angular distributions of emitted neutrons by taking account of fission and (n,Xn) cross sections as competing reaction cross sections. In this calculation radiative capture strength functions were normalized to measured capture cross sections around 100 keV or calculated from Γ_γ and D_{obs} obtained from resolved resonance parameters.

Angular distributions of elastically and inelastically scattered neutrons were taken from the CASTHY calculation. For other reactions, isotropic distributions were assumed in the laboratory system.

Energy distributions were also given on the basis of the evaporation model. Nuclear temperature was estimated from level density parameters for each nuclide. Fission neutron spectra were given in the evaporation form with the temperature obtained from systematics by Smith et al. /15/.

Optical Potential Parameters

The spherical optical and statistical models were used to calculate unknown total, elastic scattering and compound nucleus formation cross sections, and angular distributions of emitted neutrons. The parameters listed below were determined /4/ to reproduce the total cross section of Am-241 measured by Phillips and Howe /16/.

$V = 43.4 - 0.107E_n$
$W_s = 6.95 - 0.339E_n + 0.0531E_n^2$
$V_{so} = 7.0$
$r_0 = r_{so} = 1.282$
$r_s = 1.290$
$a = a_{so} = 0.60$
$b = 0.5$

Comparison of calculated total cross section with the measured data is made in Fig. 1.

For Am-242 and 244, another set of parameters /17/ was used because the compound nucleus formation cross section calculated from the above parameters was smaller than the measured fission cross section.

$V = 42.0 - 0.107E_n$
$W_s = 9.0 - 0.339E_n + 0.0531E_n^2$
$V_{so} = 7.0$
$r_0 = r_{so} = 1.282$
$r_s = 1.290$
$a = a_{so} = 0.60$
$b = 0.5$

Level Density Parameters

Level density parameters were adopted from Gilbert and Cameron /18/. Those for some isotopes were modified with LEVDENS /19/ based on resonance-level spacings and number of low-lying excited levels.

Level Scheme

Information on excited levels was mainly taken from Nuclear Data Sheets and ENSDF.

Data of Some Important Am Isotopes

Am-241

The resonance parameters were taken from JENDL-2 /20/, because no new experimental analysis exists and JENDL-2 reproduces well the fission cross section measured by Dabbs et al. /21/ at the thermal neutron energy. The unresolved resonance parameters were determined so that they might reproduce the capture cross section measured by Vanpraet et al. /22/ and the fission cross section by Dabbs et al.

New experimental fission-cross section data by Dabbs et al. are lower than those of JENDL-2 by about 10 %. In the present evaluation, the cross section was replaced with the data of Dabbs et al. in the all energy range. The capture cross section was normalized to 1.7 barns at 60 keV so as to reproduce the experimental data of Vanpraet et al. /22/. The present evaluation is compared with experimental data in Fig. 2.

Am-242m

New measurements /23,24/ have been reported for the fission cross section in the wide energy range from thermal to 20 MeV. However, these two measurements were systematically inconsistent by about 20 %. The reason of this is not clear so far. In the present evaluation, the data of Browne et al. /23/ were mainly adopted. Figure 3 shows the fission cross section below 20 eV.

In the resonance region, Browne et al. /23/ determined parameters for 48 resonances up to 19.7 eV. Above this energy, many resonance shapes were measured. After smoothing the experimental data, average resonance parameters were estimated with ASREP up to 30 keV. In the smooth region, the fission cross section was obtained by spline-fitting to the experimental data /23/, and the capture cross section was calculated by assuming Γ_γ of 50 meV and D_{obs} of 0.4 eV.

Am-243

Values of fission width in JENDL-2 were updated by adopting the data of Knitter and Budtz-Jørgensen /25/. Those of low-lying resonances were adjusted a little so that the thermal fission cross section of 0.2 barns might be reproduced. The same unresolved resonance parameters as those of JENDL-2 were adopted.

Recent experimental data of fission cross section above 100 keV are lower than JENDL-2 which was based on the data by Behrens and Browne /26/. In the present evaluation, the data of JENDL-2 /20/ were adopted below 100 keV, while spline-fitting was performed to the recent data /25,27,28/ above 100 keV. The fission cross section in MeV region is shown in Fig. 4.

The capture cross section was calculated with CASTHY by normalizing it to 2.2 barns at 30 keV. The result is in very good agreement with the new data of Weston and Todd /29/.

Conclusions

Evaluation of neutron nuclear data of transplutonium nuclides have been performed. The data of Am isotopes were re-evaluated on the basis of the recent experimental data. The results of the present evaluation will be stored in JENDL-3. In Table 1, thermal cross sections and resonance integrals are compared with recommended values by Mughabghab /30/.

The evaluated data of fission and capture cross sections of important nuclides are reliable. However, evaluated data of such as (n,Xn) cross sections whose experimental data are not existing are very descrepant among available evluated data liblaries. Experimental and theoretical efforts seem to be needed more on these quantities.

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Table 1. The 2200-m/s cross sections and resonance integrals

	2200-m/s cross sections				Resonance integrals			
	capture		fission		capture		fission	
Nuclide	Present	Ref. 30	Present	Ref. 30	Present	Ref. 30	Present	Ref. 30
Am-241	600.4	587(12)	3.02	3.20(0.09)	1300	1425(100)	14.7	14.4(1.0)
Am-242	5500	-	2100	2100(200)	391	-	1260	-
Am-242m	1340	2000(600)	6620	6950(280)	246	-	1560	1800(65)
Am-243	78.5	75.1(1.8)	0.228	0.1983(0.0043)	1820	1820(70)	7.59	9(1)
Am-244	600	-	2300	2300(300)	316	-	1260	-
Am-244m	400	-	1600	1600(300)	316	-	1260	-
Cm-242	15.92	16(5)	5	< 5	116	110(20)	11.1	-
Cm-243	131.3	130(10)	512.3	617(20)	404	215(20)	1750	1570(100)
Cm-244	14.4	15.2(1.2)	1.18	1.04(0.20)	594	650(30)	18.4	12.5(2.5)
Cm-245	346.3	369(17)	2001	2145(58)	108	101(8)	799	840(40)
Cm-246	1.33	1.22(0.16)	0.142	0.14(0.05)	103	121(7)	9.5	10.2(0.4)
Cm-247	59.9	57(10)	97.0	81.9(4.4)	495	530(30)	769	760(50)
Cm-248	2.57	2.63(0.26)	0.37	0.37(0.05)	257	270(15)	17.5	15
Cm-249	1.60	1.6(0.8)	0.82	-	215	-	139	-
Bk-249	709.6	746(40)	3.92	-	1130	1100(100)	12.1	-
Bk-250	353	350	959	960(150)	199	-	517	-
Cf-249	504.5	497(21)	1666	1642(33)	695	765(35)	2220	2380(85)
Cf-250	1779	2034(200)	4.09	-	8425	11600(500)	27.8	-
Cf-251	2878	2850(150)	4935	4895(250)	1610	1600(30)	2780	5900(100)
Cf-252	20.7	20.4(1.5)	33.0	32(4)	47.4	43.5(3.0)	111	110(30)

Values in ( ) are errors in barns.

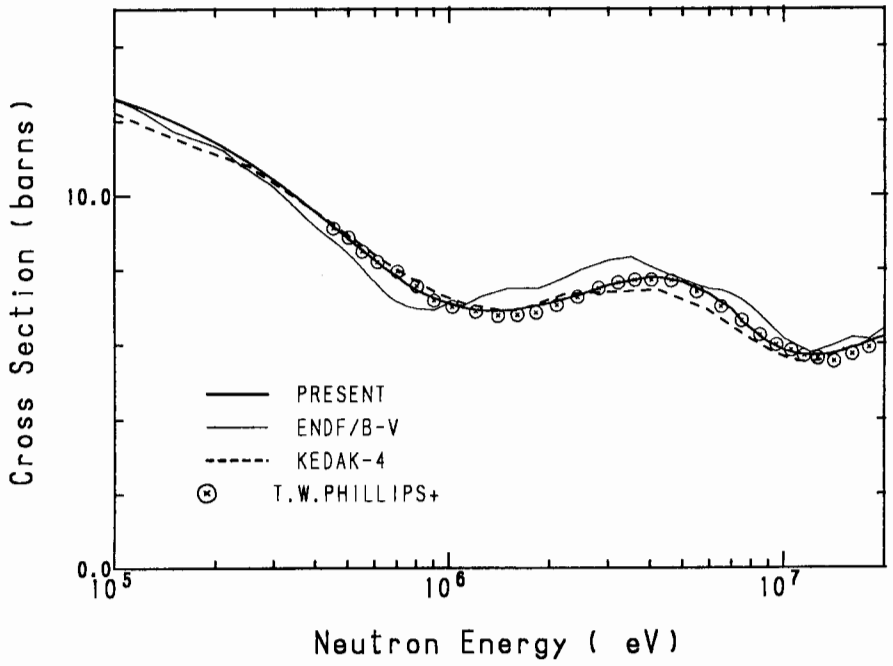

Fig. 1 Total cross section of Am-241

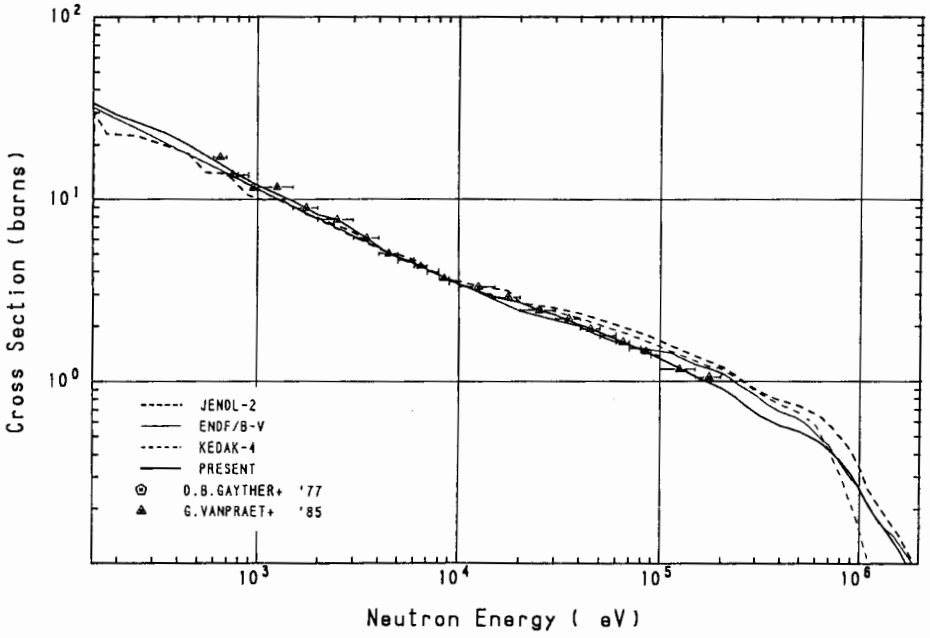

Fig. 2 Capture cross section of Am-241

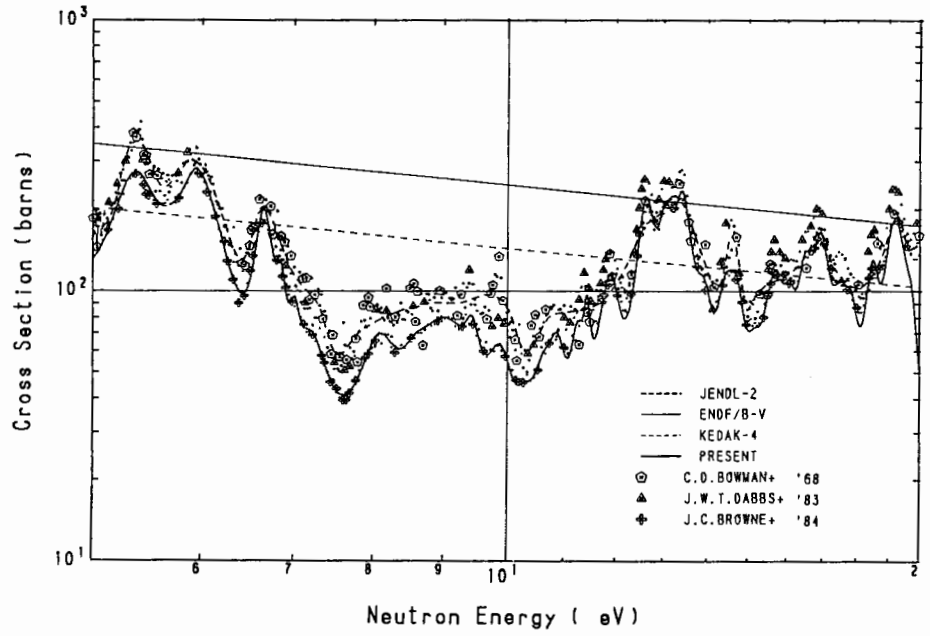

Fig. 3 Fission cross section of Am-242m

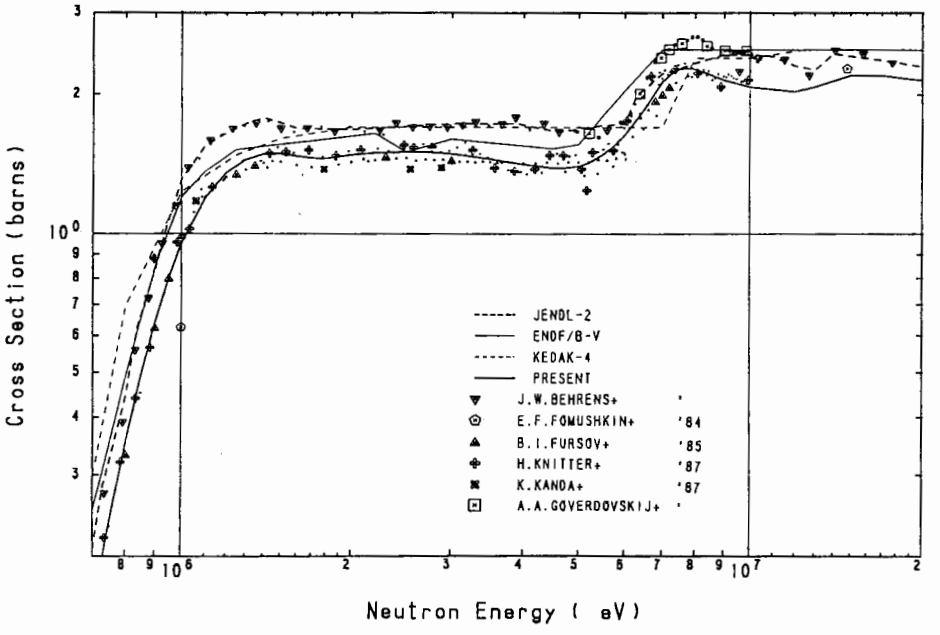

Fig. 4 Fission cross section of Am-243