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REVISED EVALUATIONS FOR ENDF/B-VI REVISION 2

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The purpose of this paper is to report on revised cross-section evaluations for 17 nuclides that have been prepared for ENDF/B-VI Revision 2. The nuclides considered include five fission products and various isotopes of cadmium and hafnium. The previous ENDF/B-VI evaluations for these 17 nuclides were carried over from ENDF/B-V and were completed in the 1974–1980 time period. By utilizing the experimental data that have become available since 1980 (e.g., Refs. 1–11), the revised evaluations will result in significant improvements in the evaluated nuclear data files. The primary emphasis was placed on the resolved and unresolved resonance regions, but new experimental data were also used to improve the cross sections for energies above the unresolved resonance region. Negative elastic scattering cross sections were encountered in some of the previous evaluations; since the revised evaluations use multilevel Breit-Wigner (MLBW) parameters, rather than single-level Breit-Wigner (SLBW), this problem is eliminated.

The 17 nuclides with revised evaluations are shown in Table 1 along with values for selected parameters. The nuclides ^{101}Ru, ^{102}Ru, ^{143}Nd, ^{145}Nd, and ^{150}Sm are important fission products. The nuclide ^{143}Nd accounts for a significant fraction of the fission-product absorption rate in thermal reactors, while ^{101}Ru accounts for about 10% of the fission-product absorption in a typical fast reactor spectrum for a ^{239}Pu fueled system. The new evaluation of the ^{101}Ru resolved resonance range is revised and extended from 120 to 1000 eV. The capture cross section is revised for energies above 1 keV and follows the data of Macklin[3] between 3 and 700 keV. For the ^{102}Ru evaluation, the number of resolved resonances is increased from 3 in the previous evaluation to 149 in the revised evaluation. In the new ^{143}Nd evaluation, the resolved resonance range is extended from 595.07 to 5285 eV and the number of resolved resonances is increased from 18 to 149. The total and elastic cross sections are revised above 5285 eV. The capture cross section is revised above 1 MeV, and the inelastic cross section is also changed. The resolved resonance range for the new ^{145}Nd evaluation is also revised and has been extended from 1457 to 4140 eV. The number of resonances is increased

Table 1. Selected Parameters by Nuclide

Nuclide	MAT	NR	EHIR	D_0	S_0	σ_γ^0	I_γ
Ru-101	4440	40	1000	20.42	0.59	3.413	111.7
Ru-102	4443	149	3400	360	0.45	1.228	4.316
Cd-106	4825	75	6000	110	1.00	1.120	14.20
Cd-108	4831	82	6100	100	1.44	1.100	16.98
Cd-110	4837	103	7176	155	0.50	11.01	41.36
Cd-112	4843	118	7350	190	0.50	2.195	13.50
Cd-114	4849	85	8000	235	0.64	0.336	13.15
Cd-116	4855	48	9000	390	0.16	0.075	1.730
Nd-143	6028	149	5285	32.48	3.50	323.1	129.6
Nd-145	6034	213	4140	17.32	4.00	41.89	229.7
Sm-150	6243	23	1600	48	3.60	103.4	337.8
Hf-174	7225	11	230	21	2.80	561.8	355.4
Hf-176	7231	24	1080	35	2.50	13.76	401.3
Hf-177	7234	180	700	2.36	1.70	373.5	7175
Hf-178	7237	25	2100	51	2.20	84.03	1905
Hf-179	7240	71	450	4.36	1.80	43.59	548.3
Hf-180	7243	155	10000	100	1.90	34.59	34.47

MAT - ENDF/B material number
NR - the number of resolved resonances
EHIR - the upper limit of the resolved resonance range (eV)
D_0 - the s-wave average level spacing in the unresolved resonance range (eV)
S_0 - the s-wave neutron strength function in the unresolved resonance range, given in units of 10^{-4}
σ_γ^0 - capture cross section measured at 2200 m/s (barns)
I_γ - capture resonance integral (barns)

from 79 to 213. The thermal capture cross section and the capture resonance integral are only slightly changed from the previous evaluation. The ^{150}Sm resolved resonance range in the new evaluation is revised and extended from 581.7 to 1454 eV. The bound level at -3.2 eV (Ref. 5) is not included. Including both the -3.2- and -10.2-eV bound levels gives a value of the thermal capture cross section which is too high compared to the measured value. Including only the -10.2-eV level gives a thermal capture cross section of 103.4 barns and a total cross section of 122.2 barns. The total, elastic, and inelastic cross sections are revised above 100 keV and the (n,2n) cross section was added.

An important application of the elements cadmium and hafnium are their use in control rods in nuclear reactors. For this reason, it is desirable to determine these self-shielded absorption cross sections to high accuracy. Individual cross sections for each isotope are required for control rod burnup calculations since the isotopic number densities vary as a function of burnup. An improved ^{108}Cd evaluation is also needed[12] to help optimize the production of the medical isotope ^{109}Cd. The most significant changes for the revised cadmium evaluations are:

1. ^{106}Cd and ^{108}Cd did not have resolved resonance parameters in the previous ENDF/B-VI files. In the revised evaluations the resolved resonance ranges extend to 6 keV for ^{106}Cd and 6.1 keV for ^{108}Cd. The capture resonance integral of ^{108}Cd is increased from 4.3 barns in the previous evaluation to 16.98 barns in the revised evaluation.
2. For ^{110}Cd the upper limit of the resolved resonance range is unchanged, but the number of resolved resonances is increased from 68 to 103.
3. For ^{112}Cd, ^{114}Cd, and ^{116}Cd the upper limit of the resolved range and the number of resonances are increased for each of the 3 isotopes. The capture resonance integral of ^{114}Cd is changed from 19.25 barns in the previous evaluation to 13.15 barns in the new evaluation.

A paper on the revised hafnium evaluations[13] for ENDF/B-VI has been given previously. Based on the Cross-Section Evaluation Working Group (CSEWG) Phase 1 review and other comments which were received, revisions to the original work have been made. These include the following:

1. A minor change was made in the ^{174}Hf unresolved resonance parameters.
2. The parameters of the first resonance of ^{176}Hf at 7.886 eV are revised based on the data of Moxon.[11] The original bound level is deleted and two new bound levels are inserted. The revised parameters result in significant changes in the thermal cross sections and the capture resonance integral. The revised thermal capture cross section and capture RI are given in Table 1.
3. The parameters of the ^{179}Hf resonance at 5.68 eV are revised. The revised thermal cross sections are 50.66 barns, 7.07 barns, and 43.59 barns for total, elastic, capture, respectively. The revised capture resonance integral is 548 barns.

Average capture cross sections in 31 energy groups between 3 keV and 2 MeV for ^{101}Ru, ^{102}Ru, and the six isotopes of cadmium are given in Table 2. The revised evaluations are in much better agreement with the latest available experimental cross sections and are also significantly different from the previous evaluations. The improved evaluations described in this paper will result in more accurate calculations for applications such as control rod burnup studies or fast reactor calculations where the energy range 3 keV to 2 MeV is the most important energy range.

Table 2. Average Capture Cross Sections (mb)

E(keV)	^{101}Ru	^{102}Ru	^{106}Cd	^{108}Cd	^{110}Cd	^{112}Cd	^{114}Cd	^{116}Cd
3- 4	2427	829	1347	1204	816	850	440	213
4- 6	2110	502	1322	1102	569	636	360	318
6- 8	1861	433	1183	907	513	517	385	162
8- 10	1699	457	1068	848	464	473	324	194
10- 15	1506	379	931	720	399	397	269	167
15- 20	1308	276	792	596	334	324	218	135
20- 30	1109	218	657	482	273	258	172	107
30- 40	926	171	537	385	221	206	137	85
40- 60	755	134	428	302	177	165	108	69
60- 80	613	109	339	235	144	134	88	56
80-100	525	97	284	195	125	117	77	49
100-150	441	87	232	149	118	109	71	46
150-200	352	80	188	109	117	108	71	45
200-300	275	78	144	97	118	110	72	46
300-400	198	78	121	99	120	114	74	47
400-500	152	71	110	97	123	113	72	43
500-600	123	59	116	94	126	111	69	39
600-700	101	54	104	92	128	109	67	35
700-800	84	53	83	91	128	110	68	35
800-900	70	54	77	90	125	113	72	37
900-1000	62	57	78	90	122	115	76	40
1000-1100	56	60	81	92	125	117	77	41
1100-1200	52	62	87	97	133	118	76	41
1200-1300	49	64	93	102	141	119	75	41
1300-1400	47	65	99	107	149	120	73	41
1400-1500	45	67	104	111	157	120	72	41
1500-1600	44	68	104	116	164	121	71	41
1600-1700	42	69	99	117	162	117	69	40
1700-1800	41	69	94	114	151	109	64	39
1800-1900	40	69	89	111	141	101	61	37
1900-2000	39	69	85	109	132	95	57	36

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