SG21 Report 2004

Assessment of Neutron Cross Section Evaluations for the Bulk of Fission Products

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Abstract

Since the last WPEC meeting, SG21 reviewed neutron cross-section evaluations for remaining 104 materials completing thus reviews for all 211 available materials in the fission products range. Results were discussed at the Workshop held on April 19-23, 2004, BNL, and final recommendations for best evaluations were reached for all materials. In addition, recommendations were made on 7 new materials. Actual data files should be produced by a follow-up subgroup.

1. Introduction

Neutron cross sections of fission products (FPs) constitute a considerable part of the major evaluated nuclear data libraries. Thus, in ENDF/B-VI release 8 (October 2001), there are 200 materials that fall into the range of fission products nuclei (defined as Z = 31 - 68). This should be compared with the total of 328 materials included in ENDF/B-VI.

Often, evaluations of many of these materials have not been revised for a long period of time. As a consequence, analysis of 200 fission products evaluations in ENDF/B-VI file reveals the following situation:

- 65% evaluations have been performed more than 20-25 years ago,
- 55% evaluations use isotropic neutron elastic angular distribution,
- 30% evaluations use point-wise data in neutron resonance region, and
- 30% evaluations use single-level Breit-Wigner representation for neutron resonances.

In April 2001, SG21 has been established to address this problem. The mission of SG21 is to assess neutron cross sections for fission products by reviewing all available evaluations, making use of experimental data in the EXFOR (CSISRS) library as well as considering adopted evaluation methodology. This procedure is expected to yield useful results for the bulk of fission products. It is understood that it is likely to be insufficient for most important

fission products (20-40 nuclides, depending on the application), where validation methods should be adopted.

In first 2 years, SG21 established its review methodology and reviewed 107 materials. As described in the present report, during the last year, since WPEC meeting in San Diego, May 2003, SG21 reviewed remaining 104 materials and completed its work.

2. Activities during May 2003 – April 2004

Reviews

104 remaining materials were reviewed according to the methodology established earlier. SG21 reviewers analyzed each of these materials, and produced reports with independent recommendations for resonance region and fast neutron region.

Summary of individual contributions to 211 reviews is given in Table 1. The three most productive reviewers were T. Nakagawa (29 materials), followed by K. Shibata (26) and I. Sirakov (24).

Table 1. Summary of SG21 reviews.

Project	**Name**	**Number of Reviews**
ENDF/B	Sirakov	24
	Chang	20
	Oblozinsky	17
	Herman	14
		Subtotal 75
JENDL	Nakagawa	29
	Shibata	26
	Kawai	4
		Subtotal 59
BROND	Pronyaev	22
	Ignatyuk	13
		Subtotal 35
CENDL	Sheng	22
	Zhuang	20
		Subtotal 42
Total		***211***

Workshop

SG21 Workshop was held on April 19 – 23, 2004 at BNL. Six scientists attended the workshop, representing 3 out of 4 projects actively involved in SG21: ENDF/B (P.

Oblozinsky, M. Herman, S. Mughabghab), JENDL (T. Nakagawa, O. Iwamoto) and BROND (V. Pronyaev). Status reports on fission products evaluations in all 5 major data libraries were presented or delivered in writing: ENDF/B-VI & VII, P. Oblozinsky; JENDL-3.3, T. Nakagawa; BROND-3, V. Pronyaev; JEFF-3.0, R. Jacqmin and CENLD-3, Ge Zhigang).

The Workshop discussed review reports for each material, took into account new BNL-325 evaluations recently performed by S. Mughabghab [1], looked into inter-comparison plots, considered other information, and reached consensus on best evaluations for all 211 currently available materials. In addition, it made recommendations for 7 entirely new materials. For more detailed discussion see Section 3.

Webpage

SG21 Web page, www.nndc.bnl.gov/sg21/, has been maintained by BNL. Since May 2003, the following additions and updates were made:

- **Set of 211 Reviews (18 in 2000/2001, 89 in 2002/2003, and 104 in 2003/04).** This part provides links to all reviews prepared by reviewers of SG21.

- **Workshop.** Minutes of the Workshop, BNL, April 19 – 23, 2004 [2]. This includes all presentations and reports, summary recommendations for 218 materials, conclusions of the Workshop and draft proposal of the follow-up subgroup.

3. Summary Recommendations

As shown in Table 2, the most frequently recommended library was JENDL-3.3. This is not surprising, considering that JENDL-3.3 is based on evaluations performed some 10-12 years ago that employed up-to-date physics and methodology. This is followed by CENDL-3, released in 2001 (fission products only), that in general offers solid evaluations in fast neutron region. Out of 29 materials submitted to ENDF/B-VII, to be released in December 2005, all were found good and were recommended, with some improvements in resonance region recommended for 2 materials. Fission products evaluations in ENDF/B-VI are often obsolete, hence, they were recommended in limited number of cases. Other two libraries, JEF-2.2 (JEFF-3.0) and BROND-2 were recommended exceptionally only.

Of particular importance for final recommendations are new BNL-325 evaluations in thermal, resolved resonance and unresolved resonance regions, currently under completion by S. Mughabghab [1]. These new evaluations were recommended for 107 materials, on top of it they were already included in 29 new evaluations submitted to ENDF/B-VII.

Table 2. Summary of recommended libraries.

Library (Data Source)	Full File	Resonance Region	Fast Region
ENDF/B-VI	1	18	13
ENDF/B-VII	27	-	2
JEFF-3.0	1	1	-
JENDL-3.3	44	4	66
CENDL-3	10	3	27
BROND-2	1	1	1
New BNL-325	-	107	-
EMPIRE	-	-	25
Total	**84**	**134**	**134**

In 25 instances, evaluations in fast neutron region by the nuclear reaction model code Empire were recommended. In general, these are cases where little or no data are available. It is assumed that, due to up-to-date physics and parameterization, Empire is well suited to predict unknown cross sections [3].

Table 2 suggests that complete data files are readily available for 84 materials. For the remaining 134 materials, merging of files from 2 different sources must be performed, including a few cases where data from 3 sources should be merged.

SG21 recommendations are summarized in Table 3. This table shows recommendations for 218 materials (211 existing + 7 new) in the fission products range, Z = 31 – 68, as discussed and approved by SG21 Workshop, April 19-23, 2004. In case that a single library or data source is shown, then recommended was a specific file in full. If two sources are shown, then different recommendations for slow and fast neutron regions were made, meaning that merging of two files is required.

Table 3. Summary recommendations for 211 existing and 7 new materials.

No	Z	Nuclide	Reviewer	Workshop Result	Comment
1	31	31-Ga-69	Oblozinsky	New-BNL + JENDL-3.3	
2		31-Ga-71	Oblozinsky	CENDL-3	
3	32	32-Ge-70	Herman	ENDF/B-VII	
4		32-Ge-72	Herman	ENDF/B-VII	
5		32-Ge-73	Herman	ENDF/B-VII	
6		32-Ge-74	Herman	ENDF/B-VII	
7		32-Ge-76	Herman	ENDF/B-VII	
8	33	33-As-75	Herman	New-BNL + JENDL-3.3	
9	34	34-Se-74	Sirakov	JENDL-3.3	

10		34-Se-76	Sirakov	JENDL-3.3	
11		34-Se-77	Sirakov	JENDL-3.3	
12		34-Se-78	Sirakov	JENDL-3.3	
13		34-Se-79	Sirakov	JENDL-3.3	
14		34-Se-80	Sirakov	JENDL-3.3	
15		34-Se-82	Sirakov	New-BNL + JENDL-3.3	
16	35	35-Br-79	Oblozinsky	JENDL-3.3	
17		35-Br-81	Oblozinsky	New-BNL + JENDL-3.3	
18	36	36-Kr-78	Sirakov	New-BNL + JENDL-3.3	
19		36-Kr-80	Sirakov	JENDL-3.3	
20		36-Kr-82	Sirakov	New-BNL + JENDL-3.3	
21		36-Kr-83	Sirakov	CENDL-3	
22		36-Kr-84	Sirakov	New-BNL + JENDL-3.3, RRP up to 100 keV	
23		36-Kr-85	Sirakov	JENDL-3.3 + EMPIRE	
24		36-Kr-86	Sirakov	New-BNL + JENDL-3.3	
25	37	37-Rb-85	Sirakov	JENDL-3.3	
26		37-Rb-86	Oblozinsky	ENDF/B-VI + EMPIRE	
27		37-Rb-87	Sirakov	JENDL-3.3	
28	38	38-Sr-84	Shen	New-BNL + EMPIRE	
29		38-Sr-86	Shen	New-BNL + JENDL-3.3	
30		38-Sr-87	Shen	JENDL-3.3	
31		38-Sr-88	Sirakov	New-BNL + CENDL-3	
32		38-Sr-89	Shen	CENDL-3	
33		38-Sr-90	Shen	JENDL-3.3	
34	39	39-Y- 89	Shen	JENDL-3.3	
35		38-Y- 90	Shen	ENDF/B-VI + EMPIRE	
36		39-Y- 91	Shen	JENDL-3.3	
37	40	40-Zr-90	Chang	BROND-2	
38		40-Zr-91	Chang	New-BNL + JENDL-3.3	
39		40-Zr-92	Chang	New-BNL + BROND-2	
40		40-Zr-93	Chang	BROND-2 + JENDL-3.3	
41		40-Zr-94	Chang	ENDF/B-VI + JENDL-3.3	
42		40-Zr-95	Sirakov	JENDL-3.3	
43		40-Zr-96	Chang	New-BNL + JENDL-3.3	
44	41	41-Nb-93	Shibata	JENDL-3.3 + ENDF/B-VI	
45		41-Nb-94	Shibata	JENDL-3.3	
46		41-Nb-95	Kawai	JENDL-3.3	
47	42	42-Mo-92	Chang	JENDL-3.3	
48		42-Mo-94	Chang	New-BNL + JENDL-3.3	
49		42-Mo-95	Chang	ENDF/B-VII	
50		42-Mo-96	Chang	JENDL-3.3	
51		42-Mo-97	Chang	New-BNL + JENDL-3.3	
52		42-Mo-98	Chang	JENDL-3.3	

53		42-Mo-99	Chang	JENDL-3.3	
54		42-Mo-100	Chang	CENDL-3	
55	43	43-Tc-99	Oblozinsky	New-BNL + ENDF/B-VII	
56	44	44-Ru-96	Nakagawa	JENDL-3.3	
57		44-Ru-98	Nakagawa	JENDL-3.3	
58		44-Ru-99	Nakagawa	JENDL-3.3	
59		44-Ru-100	Nakagawa	JENDL-3.3 + CENDL-3	
60		44-Ru-101	Nakagawa	ENDF/B-VII	
61		44-Ru-102	Nakagawa	New-BNL + CENDL-3	
62		44-Ru-103	Nakagawa	New-BNL + CENDL-3	
63		44-Ru-104	Nakagawa	CENDL-3	
64		44-Ru-105	Nakagawa	CENDL-3	
65		44-Ru-106	Nakagawa	JENDL-3.3	
66	45	45-Rh-103	Shibata	New-BNL + ENDF/B-VII	
67		45-Rh-105	Shibata	ENDF/B-VI + CENDL-3	
68	46	46-Pd-102	Herman	New-BNL + ENDF/B-VI	
69		46-Pd-104	Shibata	New-BNL + ENDF/B-VI	
70		46-Pd-105	Shibata	ENDF/B-VII	
71		46-Pd-106	Shibata	New-BNL + ENDF/B-VI	
72		46-Pd-107	Shibata	JENDL-3.3	
73		46-Pd-108	Shibata	New-BNL + ENDF/B-VI	
74		46-Pd-110	Shibata	New-BNL + ENDF/B-VI	
75	47	47-Ag-107	Shen	New-BNL + JENDL-3.3	
76		47-Ag-109	Shen	ENDF/B-VII	
77		47-Ag-110m	Shen	New-BNL + JENDL-3.3	
78		47-Ag-111	Shen	ENDF/B-VI + EMPIRE	
79	48	48-Cd-106	Oblozinsky	New-BNL + JENDL-3.3	
80		48-Cd-108	Oblozinsky	New-BNL + ENDF/B-VI	
81		48-Cd-110	Herman	New-BNL + ENDF/B-VI	
82		48-Cd-111	Herman	New-BNL + JENDL-3.3	
83		48-Cd-112	Herman	New-BNL + ENDF/B-VI	
84		48-Cd-113	Herman	New-BNL + CENDL-3	
85		48-Cd-114	Herman	ENDF/B-VI	
86		48-Cd-115m	Oblozinsky	ENDF/B-VI + EMPIRE	
87		48-Cd-116	Oblozinsky	New-BNL + ENDF/B-VI	
88	49	49-In-113	Zhuang	New-BNL + JENDL-3.3	
89		49-In-115	Oblozinsky	New-BNL + JENDL-3.3	
90	50	50-Sn-112	Shibata	New-BNL + JENDL-3.3	
new		50-Sn-113	none	New-BNL + EMPIRE	New material
91		50-Sn-114	Shibata	New-BNL + JENDL-3.3	
92		50-Sn-115	Shibata	New-BNL + JENDL-3.3	
93		50-Sn-116	Shibata	New-BNL + JENDL-3.3	
94		50-Sn-117	Shibata	New-BNL + JENDL-3.3	
95		50-Sn-118	Shibata	New-BNL + JENDL-3.3	

96		50-Sn-119	Shibata	New-BNL + JENDL-3.3	
97		50-Sn-120	Shibata	New-BNL + JENDL-3.3	
98		50-Sn-122	Shibata	New-BNL + JENDL-3.3	
99		50-Sn-123	Shibata	JENDL-3.3	
100		50-Sn-124	Shibata	New-BNL + JENDL-3.3	
101		50-Sn-125	Shibata	ENDF/B-VI + EMPIRE	
102		50-Sn-126	Shibata	JENDL-3.3	
103	51	51-Sb-121	Shibata	New-BNL + CENDL-3	
104		51-Sb-123	Shibata	New-BNL + CENDL-3	
105		51-Sb-124	Zhuang	JENDL-3.3	
106		51-Sb-125	Kawai	JENDL-3.3	
107		51-Sb-126	Zhuang	ENDF/B-VI + EMPIRE	
108	52	52-Te-120	Zhuang	JENDL-3.3	
109		52-Te-122	Zhuang	New-BNL + JENDL-3.3	
110		52-Te-123	Zhuang	New-BNL + JENDL-3.3	
111		52-Te-124	Zhuang	New-BNL + JENDL-3.3	
112		52-Te-125	Zhuang	New-BNL + JENDL-3.3	
113		52-Te-126	Zhuang	New-BNL + JENDL-3.3	
114		52-Te-127m	Zhuang	JENDL-3.3	
115		52-Te-128	Zhuang	New-BNL + JENDL-3.3	
116		52-Te-129m	Zhuang	JENDL-3.3	
117		52-Te-130	Zhuang	New-BNL + CENDL-3	
118		52-Te-132	Zhuang	ENDF/B-VI + EMPIRE	
119	53	53-I- 127	Pronyaev	New-BNL + ENDF/B-VI	
120		53-I- 129	Pronyaev	New-BNL + JENDL-3.3	
121		53-I- 130	Herman	ENDF/B-VI + EMPIRE	
122		53-I- 131	Pronyaev	JENDL-3.3	
123		53-I- 135	Pronyaev	ENDF/B-VI + CENDL-3	
124	54	54-Xe-123	Pronyaev	CENDL-3	
125		54-Xe-124	Pronyaev	New-BNL + CENDL-3	
126		54-Xe-126	Pronyaev	New-BNL + JENDL-3.3	
127		54-Xe-128	Zhuang	New-BNL + JENDL-3.3	
128		54-Xe-129	Pronyaev	New-BNL + JENDL-3.3	
129		54-Xe-130	Zhuang	New-BNL + ENDF/B-VI	
130		54-Xe-131	Shen	ENDF/B-VII	
131		54-Xe-132	Zhuang	New-BNL + CENDL-3	
132		54-Xe-133	Zhuang	JENDL-3.3	
133		54-Xe-134	Zhuang	New-BNL + CENDL-3	
134		54-Xe-135	Pronyaev	New-BNL + JENDL-3.3	
135		54-Xe-136	Zhuang	New-BNL + CENDL-3	
136	55	55-Cs-133	Sirakov	ENDF/B-VII	
137		55-Cs-134	Shen	New-BNL + JENDL-3.3	
138		55-Cs-135	Sirakov	New-BNL + JENDL-3.3	
139		55-Cs-136	Sirakov	SC + JENDL-3.3	Res paramaters to

					be checked by Mughabghab
140		55-Cs-137	Sirakov	JENDL-3.3	
141	56	56-Ba-130	Oblozinsky	New-BNL + JENDL-3.3	
142		56-Ba-132	Sirakov	New-BNL + JENDL-3.3	
new		56-Ba-133	none	New-BNL + EMPIRE	New material
143		56-Ba-134	Pronyaev	New-BNL + JENDL-3.3	
144		56-Ba-135	Pronyaev	New-BNL + JENDL-3.3	
145		56-Ba-136	Pronyaev	New-BNL + JENDL-3.3	
146		56-Ba-137	Pronyaev	New-BNL + JENDL-3.3	
147		56-Ba-138	Pronyaev	New-BNL + CENDL-3	
148		56-Ba-140	Sirakov	JEFF-3.0	
149	57	57-La-138	Nakagawa	JENDL-3.3	
150		57-La-139	Nakagawa	New-BNL + CENDL-3	
151		57-La-140	Nakagawa	ENDF/B-VI + EMPIRE	
152	58	58-Ce-136	Nakagawa	New-BNL + EMPIRE	
153		58-Ce-138	Nakagawa	New-BNL + EMPIRE	
new		58-Ce-139	none	New-BNL + EMPIRE	New material
154		58-Ce-140	Nakagawa	New-BNL + JENDL-3.3	
155		58-Ce-141	Nakagawa	JENDL-3.3 (SC) + CENDL-3	Res parameters to be checked by Mughabghab
156		58-Ce-142	Nakagawa	New-BNL + JENDL-3.3	
157		58-Ce-143	Nakagawa	ENDF/B-VI + EMPIRE	
158		58-Ce-144	Nakagawa	JENDL-3.3	
159	59	59-Pr-141	Oblozinsky	ENDF/B-VII	
160		59-Pr-142	Oblozinsky	New-BNL + EMPIRE	
161		59-Pr-143	Oblozinsky	New-BNL + JENDL-3.3	
162	60	60-Nd-142	Kawai	JENDL-3.3 (SC) + CENDL-3 (ENDF/B-VI for capture)	Res parameters to be checked by Mughabghab. Merge involves 3 sources.
163		60-Nd-143	Nakagawa	ENDF/B-VII	
164		60-Nd-144	Nakagawa	JENDL-3.3	
165		60-Nd-145	Kawai	ENDF/B-VII	
166		60-Nd-146	Nakagawa	New-BNL + CENDL-3 (JEFF-3.0 for inelastic, capture)	Merge involves 3 sources
167		60-Nd-147	Nakagawa	New-BNL + CENDL-3	
168		60-Nd-148	Nakagawa	New-BNL + JENDL-3.3 (CENDL-3 for total)	Merge involves 3 sources
169		60-Nd-150	Nakagawa	New-BNL + CENDL-3	
170	61	61-Pm-147	Shen	New-BNL + JENDL-3.3	
171		61-Pm-148	Shen	New-BNL + JENDL-3.3	
172		61-Pm-148m	Oblozinsky	CENDL-3	

173		61-Pm-149	Shen	JENDL-3.3	
174		61-Pm-151	Oblozinsky	ENDF/B-VI + URP by Said + EMPIRE	Merge involves 3 sources
175	62	62-Sm-144	Ignatyuk	New-BNL + JENDL-3.3	
176		62-Sm-147	Ignatyuk	ENDF/B-VII	
177		62-Sm-148	Ignatyuk	New-BNL + JENDL-3.3	
178		62-Sm-149	Ignatyuk	ENDF/B-VII	
179		62-Sm-150	Ignatyuk	ENDF/B-VII	
180		62-Sm-151	Ignatyuk	ENDF/B-VII	
181		62-Sm-152	Ignatyuk	ENDF/B-VII	
182		62-Sm-153	Ignatyuk	JENDL-3.3	
183		62-Sm-154	Ignatyuk	CENDL-3	
184	63	63-Eu-151	Nakagawa	ENDF/B-VI + CENDL-3	
185		63-Eu-152	Nakagawa	ENDF/B-VI (up to 10 keV) + JENDL-3.3	
186		63-Eu-153	Ignatyuk	ENDF/B-VII	
187		63-Eu-154	Ignatyuk	New-BNL + CENDL-3	
188		63-Eu-155	Ignatyuk	JENDL-3.3 (SC) + CENDL-3	Res parameters to be checked by Mughabghab
189		63-Eu-156	Ignatyuk	JENDL-3.3	
190		63-Eu-157	Herman	ENDF/B-VI + EMPIRE	
191	64	64-Gd-152	Pronyaev	New-BNL + JENDL-3.3	
new		64-Gd-153	none	New-BNL + EMPIRE	New material
192		64-Gd-154	Pronyaev	New-BNL + CENDL-3	
193		64-Gd-155	Pronyaev	ENDF/B-VII	
194		64-Gd-156	Pronyaev	CENDL-3	
195		64-Gd-157	Pronyaev	ENDF/B-VII	
196		64-Gd-158	Pronyaev	New-BNL + CENDL-3	
197		64-Gd-160	Pronyaev	New-BNL + CENDL-3	
198	65	65-Tb-159	Pronyaev	New-BNL + JENDL-3.3	
199		65-Tb-160	Shibata	New-BNL + EMPIRE	
new	66	66-Dy-156	none	New-BNL + EMPIRE	New material
new		66-Dy-158	none	New-BNL + EMPIRE	New material
200		66-Dy-160	Shen	ENDF/B-VII	
201		66-Dy-161	Shen	ENDF/B-VII	
202		66-Dy-162	Shen	ENDF/B-VII	
203		66-Dy-163	Shen	ENDF/B-VII	
204		66-Dy-164	Shen	ENDF/B-VII --> Background sig and Q-values should be modified. If cannot, ENDF/B-VI + CENDL-3	Modifications in file needed.
205	67	67-Ho-165	Shibata	New-BNL + ENDF/B-VI	
new		67-Ho-166m	none	New-BNL + EMPIRE	New material
206	68	68-Er-162	Chang	JENDL-3.3	

207		68-Er-164	Chang	JENDL-3.3	
208		68-Er-166	Chang	New-BNL + JENDL-3.3	
209		68-Er-167	Chang	New-BNL + JENDL-3.3	
210		68-Er-168	Chang	New-BNL + JENDL-3.3	
211		68-Er-170	Chang	New-BNL + JENDL-3.3	

Explanation to Table 3:

- New-BNL = New BNL-325 evaluation by Said Mughabghab, including unresolved resonance parameters [1].
- SC = Resonance parameters to be checked by Said Mughabghab, BNL.
- EMPIRE = Evaluation using the code Empire is recommended.

4. Conclusions

Since its establishment in April 2001, SG21 performed a considerable job. In 3 years, the subgroup reviewed and assessed all 211 fission products cross-section materials currently available in major evaluated libraries. All findings were examined by concluding SG21 Workshop where final recommendations were achieved [2].

In accordance with its initial charge, SG21 delivered the following results:

- Review reports for all 211 available materials in the range Z = 31 – 68.
- Recommendations for best evaluations for 211 materials. In addition, recommendations were made for 7 new materials.

A considerable benefit to SG21 and thus to an overall improvement of fission products evaluations was made possible by two circumstances not foreseen at the beginning of the project:

- First, new BNL-325 evaluations are becoming available [1]. This is of exceptional importance since Mughabghab's seminal work will hardly be repeated in future.
- Second, a number of improvements in fast neutron region are feasible thanks to the power of the code Empire [3].

It should be pointed out that SG21 deliverables were reviews and recommendations. A follow-up subgroup should be established to produce actual data files including testing.

References

1. S. Mughabghab, "Neutron Cross Sections: Neutron Resonance Parameters and Thermal Cross Sections", under preparation, to be submitted to Academic Press in about December 2004.
2. Minutes of SG21 Workshop, BNL, April 19 – 23, 2004, www.nndc.bnl.gov/sg21.
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