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ASSESSMENT OF NEUTRON CROSS SECTION EVALUATIONS FOR THE BULK OF FISSION PRODUCTS

A report by the Working Party
on International Evaluation Co-operation
of the NEA Nuclear Science Committee

CO-ORDINATOR AND MONITOR

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FOREWORD

A Working Party on International Evaluation Co-operation was established under the sponsorship of the OECD/NEA Nuclear Science Committee (NSC) to promote the exchange of information on nuclear data evaluations, validation, and related topics. Its aim is also to provide a framework for co-operative activities between the members of the major nuclear data evaluation projects. This includes the possible exchange of scientists in order to encourage co-operation. Requirements for experimental data resulting from this activity are compiled. The working party determines common criteria for evaluated nuclear data files with a view to assessing and improving the quality and completeness of evaluated data.

The parties to the project are: ENDF (United States), JEFF/EFF (NEA Data Bank Member countries) and JENDL (Japan). Co-operation with evaluation projects of non-OECD countries, specifically the Russian BROND and Chinese CENDL projects, are organized through the Nuclear Data Section of the International Atomic Energy Agency (IAEA).

The following report has been issued by Subgroup 21, which was charged with the task to assess neutron cross-section evaluations for fission products. The Subgroup performed a considerable job, reviewed and assessed neutron-induced cross sections in all major evaluated nuclear data libraries. As a result, the Subgroup provided recommendations for best evaluations for 218 fission products.

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SUMMARY

Subgroup 21 reviewed neutron cross-section evaluations for a complete set of materials in the fission products range as available in major evaluated nuclear data libraries. For the purposes of the present project fission products were defined as materials with Z = 31 – 68. Considered libraries were ENDF/B-VI.8, JENDL-3.2 (or JENDL-3.3), JEF-2.2 (or JEFF 3.0), BROND-2 and CENDL-3.0.

Inter-comparison of evaluated data in 5 libraries along with comparison with experimental data retrieved from the experimental reaction database EXFOR was prepared. Altogether around 1900 plots, in general 9 plots per material were prepared and made available on www.nndc,bnl.gov/sg21.

Subgroup 21 included 10 active reviewers, making it possible to review each material individually within relatively short period of time of 3 years. Low energy region (thermal point and resonances) and fast neutron region were reviewed separately. Taken into account was history and source/authors of evaluation, graphical inter-comparison of all evaluations along with experimental data, and evaluation methodology. For each material a review report was written, describing procedure, summarizing findings and recommendations of the best evaluation for the low energy and for the fast energy regions. No attempt was made to consider data validation and integral measurements to assess the quality of evaluations.

Review reports were discussed at the Workshop held on April 19-23, 2004 in Brookhaven National Laboratory. The Workshop reached final recommendations for the best evaluations for all materials. In addition to the 211 currently available materials, recommendations were made on 7 new materials.

Altogether, Subgroup 21 produced recommendations for 218 materials in the fission product range. It is a task for the follow-up Subgroup (SG23) to use these recommendations and to prepare actual fission product library.

It is assumed that national projects will use these recommendations, as well as the library, as the source for the bulk of fission product materials (~180). It is assumed that one would resort to other criteria for selection of fission products considered to be priority for specific applications (~40 materials).

ASSESSMENT OF NEUTRON CROSS SECTION EVALUATIONS FOR THE BULK OF FISSION PRODUCTS

1. Introduction

Neutron cross sections of fission products (FPs) constitute a considerable part of major evaluated nuclear data libraries. For instance, in ENDF/B-VI release 8 (October 2001), there are 196 materials that fall into the range of fission products (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 the fission products have not been revised for a long period of time. As a consequence, analysis of almost 200 fission product evaluations in ENDF/B-VI file reveals the following situation [1]:

- 65% evaluations have been performed more than 25 years ago,
- 55% evaluations have 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, Subgroup 21 (SG21) has been established by the Working Party on International Evaluation Co-operation (WPEC) to address this problem. The mission of SG21 was to assess neutron cross sections for fission products by reviewing all available evaluations, making use of experimental data in the EXFOR (CSISRS) library and considering adopted evaluation methodology. This procedure was expected to yield useful results for the bulk of fission products. From the very beginning, it was understood that such a procedure is likely to be insufficient for the most important fission products (20-40 nuclides, depending on the application), where validation methods should be adopted.

SG21 represents the second WPEC project devoted to fission product cross-sections. In 1998, H. Gruppelaar et al completed a work under Subgroup 17 on the Status of Pseudo-Fission-Product Cross-Sections for Fast Reactors [2]. The results of SG17 partly guided the work of SG21.

In the 1st year of the project, SG21 established its review methodology and reviewed initial set of 18 materials. In the 2nd year, 89 more materials were

reviewed. Then, in the 3rd year remaining 104 materials were reviewed and final recommendations were made for all 211 materials.

The present report summarizes the results obtained by SG21. The Subgroup was established in April 2001 and completed its work in May 2004.

2. Infrastructure for review and assessment

A key part of the SG21 activity was reviewing fission product cross-section evaluations and assessment of the best evaluations. To perform a massive task of reviewing more than 200 materials, appropriate infrastructure for reviews had to be developed. To this end, SG21 webpage was created, allowing direct access to documents, evaluated libraries and inter-comparisons plots.

SG21 webpage. The page was created to facilitate review of FP evaluations, see www.nndc.bnl.gov/sg21. In addition to background information on the project and all documents about SG21 activity, it offers links to available, ongoing or planned evaluations, and provides access to graphical inter-comparison as well as review report for each FP material.

Some of the documents made available to SG21 reviewers are listed below. They were used in the reviewing process and in prioritization of SG21 work.

Thermal Neutron Capture Cross Sections, Resonance Integrals and g-Factors This important report contains new re-evaluations by S. Mughabghab (BNL) [3], February 2003. Of particular importance are new thermal capture cross sections for elements and isotopes with atomic charge numbers Z = 1-83.

Deficiencies of Neutron Cross-Section Evaluated Files for Fission Products Summary of typical deficiencies as prepared by V. Pronyaev (IAEA Vienna), March 2003.

Priority List of Fission Products The list was taken from the Final Report of the WPEC Subgroup 17 [2] (see Table 5.1 at pp. 28-30). SG17 prioritized fission products by one-group cross sections for capture in descending importance, determined by the product of the cross section and the yield of the nuclide in fast reactors. Shown in Table 1 is the list of 211 fission products plus 7 new materials, with first 40 nuclides and second 45 nuclides as prioritized by SG17.

Table 1. List of 218 fission products, with priorities identified by SG17: underscored = first 40 nuclides, italics underscored = second 45 nuclides.

31-Ga- 69, 71
32-Ge- 70, 72, 73, 74, 76
33-As- 75
34-Se- 74, 76, 77, 78, 79, 80, 82
35-Br- 79, *81*
36-Kr- 78, 80, 82, *83*, *84*, 85, 86
37-Rb- 85, 86, *87*
38-Sr- 84, 86, 87, 88, 89, 90
39-Y - 90, 90, *91*
40-Zr- 90, *91*, *92*, 93, *94*, 95, 96
41-Nb- 93, 94, 95
42-Mo- 92, 94, 95, 96, 97, 98, *99*, 100
43-Tc- 99
44-Ru- 96, 98, 99, *100*, 101, 102, 103, 104, 105, 106
45-Rh-103, *105*
46-Pd-102, *104*, 105, 106, 107, 108, *110*
47-Ag-107, 109, 110m,111
48-Cd-106, 108, 110, *111*, *112*, *113*, 114, 115m,*116*
49-In-113, *115*
50-Sn-112, 113, 114, 115, 116, 117, 118, 119, 120, 122, 123, 124, 125, 126
51-Sb-*121*, 123, 124, *125*, 126
52-Te-120, 122, 123, 124, 125, 126, 127m,*128*, *129m*,*130*, 132
53-I -127, 129, 130, *131*, 135
54-Xe-123, 124, 126, 128, 129, 130, 131,132,*133*,134,135,136
55-Cs-133, 134, 135, 136, *137*
56-Ba-130, 132, 133, 134, 135, 136, 137, 138, *140*
57-La-138, 139, 140
58-Ce-136, 138, 139, *140*, 141, *142*, 143, *144*
59-Pr-141, 142, *143*
60-Nd-142, 143, *144*, 145, 146, *147*, 148, *150*
61-Pm-147, *148*, 148m,*149*, 151
62-Sm-144, *147*, 148, 149, *150*, 151, 152, 153, *154*
63-Eu-151, 152, 153, *154*, 155, 156, 157
64-Gd-152, 153, 154, 155, *156*, *157*, *158*, 160
65-Tb-159, 160
66-Dy-156, 158, 160, *161*, 162, 163, 164
67-Ho-165, 166m
68-Er-162, 164, 166, 167, 168, 170

One-group Capture Cross-Sections for 211 Fission Products These cross-sections, calculated by I. Sirakov (BNL) following the methodology of SG17, represent capture cross sections averaged over the fast neutron spectrum as used by SG17 [2]. One-group values were calculated for all 5 libraries considered by SG21. They provide useful guidance in judging the quality of evaluation.

Evaluated libraries. Five major evaluated nuclear data libraries were used throughout the present project:

- ENDF/B-VI release 8, also Preliminary ENDF/B-VII (USA)
- JENDL-3.3, initially used was JENDL-3.2 (Japan)
- JEFF-3.0, initially used was JEF-2.2 (Europe)
- BROND-2 (Russia)
- CENDL-3.0 (China)

In the above list, official releases of the first 4 libraries were available throughout the whole SG21 project or throughout its large part.

CENDL-3.0 has not been officially released yet. However, CENDL-3.0 fission products were made available for the purposes of SG21 on October 7, 2001. It comprised 101 new evaluations for 100 isotopes and one meta-state (Z=31÷66, A=69÷164) in addition to the two fission product evaluations (^{107,109}Ag) carried over from CENDL-2. The new evaluations in CENDL-3.0 are:

- $^{69, 71}$Ga; $^{83, 84, 85, 86}$Kr; $^{85, 87}$Rb; $^{88, 89, 90}$Sr; $^{89, 91}$Y; $^{93, 95}$Zr; $^{93, 95}$Nb; $^{95, 97, 98, 100}$Mo; ^{99}Tc; $^{99, 100, 101, 102, 103, 104, 105}$Ru; $^{103, 105}$Rh; $^{105, 108}$Pd; ^{113}Cd; ^{115}In; $^{121, 123, 125}$Sb; ^{130}Te; $^{127, 129, 135}$I; $^{123, 124, 129, 131, 132, 134, 135, 136}$Xe; $^{133, 134, 135, 137}$Cs; $^{130, 132, 134, 135, 136, 137, 138}$Ba; ^{139}La; $^{136, 138, 140, 141, 142, 144}$Ce; ^{141}Pr; $^{142, 143, 144, 145, 146, 147, 148, 150}$Nd; $^{147, 148, 148m, 149}$Pm; $^{144, 147, 148, 149, 150, 151, 152, 154}$Sm; $^{151, 153, 154, 155}$Eu; $^{152, 154, 155, 156, 157, 158, 160}$Gd; and ^{164}Dy.

Graphical inter-comparison. This important reviewer tool was prepared for a complete set of 211 fission products using techniques developed by V. Zerkin, IAEA Vienna. Inter-comparison includes data from 5 evaluated data libraries as well as from EXFOR (CSISRS) experimental reaction database.

Inter-comparison plots were prepared for 7 most important reaction channels, (n, tot), (n, el), (n, inl), (n, 2n), (n, γ), (n, p), and (n, α) (MF=3, MT=1, 2, 4, 16, 102, 103, 107). Furthermore, expanded plots were provided for total and capture

cross sections. This makes altogether 9 plots per nucleus, totaling to almost 1900 plots in the whole package. An example of these plots is shown in **APPENDIX A** in connection with the sample review report for ^{102}Ru.

A convenient access to the evaluated files as well as to EXFOR files is also available form the inter-comparison plots.

3. Review methodology

The review methodology was developed in three steps. First, a sample case of ^{131}Xe was prepared by BNL, considering two basic review principles - comparison of evaluated and experimental cross sections, and analysis of evaluation methodology. Second, a trial review was undertaken for 16 materials by the whole SG21. Third, results were discussed, review procedures were refined and a common review methodology was adopted.

Adopted review procedure included 4 basic steps:

1. Perform initial analysis
    - Inspect inter-comparison plots; check all evaluations; check EXFOR data for completeness and correctness.
    - Check other experimental data since often little or no isotopic data for fission products are available in EXFOR.

2. Review low energy region
    - Analyze thermal cross sections (total, capture, elastic).
    - Analyze resolved resonance & unresolved resonance region (total, capture, elastic).

3. Review fast neutron region
    - Analyze fast neutron region, focus on total, capture, elastic inelastic, (n, 2n), (n, p) and (n, α) cross sections.
    - Analyze evaluation methodology, consider year of origin and reputation of evaluator; consider physics, codes and parameters; consider completeness of evaluation.

4. Write review report
    - Describe procedure and findings

- State recommendation for the best evaluation (separately for slow region and for fast region) or any other conclusion as appropriate.

As an example of a fairly detailed review we reproduce in **APPENDIX B** the review report for ^{102}Ru by T. Nakagawa (JAERI).

Each review was posted on SG21 webpage and made available for criticism by the rest of SG21. Once all reviews were completed, final recommendations were made by a group of reviewers that attended the closing SG21 Workshop.

4. Reviews

Review of fission product evaluations for a complete set of 211 materials was performed by SG21. Summary of reviews, supplied by four data projects participating in SG21 with contributions of individual reviewers, is given in Table 2.

Table 2. 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***

The most productive team was the ENDF team with 75 reviews. This was followed by JENDL (59 reviews), CENDL (42 reviews) and BROND (35 reviews). The three most productive reviewers were T. Nakagawa (29 materials, JENDL team), followed by K. Shibata (26 materials, JENDL team) and I. Sirakov (24 materials, ENDF team).

All reviews resulting from the SG21 activity are available on its webpage [4]. This webpage will be supported at least until the follow-up work by a new Subgroup 23, charged to create a library using SG21 recommendations, is completed.

SG21 organized a Workshop on Assessment of Fission Product Evaluations held from 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 CENDL-3, Ge Zhigang).

The Workshop discussed review reports for each material, took into account new BNL-325 evaluations recently performed by S. Mughabghab [5], looked into inter-comparison plots, considered other information, and reached consensus on the best evaluations for all 211 currently available materials. In addition, it made recommendations for 7 entirely new materials.

Minutes of the Workshop [6] include all presentations and reports, summary recommendations for 218 materials, conclusions of the Workshop and draft proposal of a follow-up subgroup.

4. Summary recommendations

Recommendations of the best evaluations for fission products, as obtained by SG21, are summarized in Table 3.

We note that ENDF project made a considerable progress in developing new ENDF/B-VII library scheduled for release in December 2005 [7]. In view of its importance, preliminary version of this library was added to SG21 considerations

prior to completing its mission. Therefore, ENDF/B-VII appears also on the list of evaluated libraries in Table 3.

As shown in Table 3, 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 only exceptionally.

Of particular importance for final recommendations are new BNL-325 evaluations in thermal, resolved resonance and unresolved resonance regions, recently completed by S. Mughabghab [5]. These new evaluations were recommended for 109 materials. On top of it they were already included in 29 new evaluations submitted to ENDF/B-VII.

Table 3. Summary of recommended libraries

Library (Data Source)	Full File	Resonance Region	Fast Region
ENDF/B-VI	1	17	13
ENDF/B-VII	27	-	2
JEFF-3.0	1	-	-
JENDL-3.3	44	7	66
CENDL-3	10	-	27
BROND-2	1	1	1
New BNL-325	-	109	-
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 most recent parameterization including Reference Input Parameter Library (RIPL-2), Empire is well suited to predict unknown cross sections [8].

Table 3 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 4. 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 [4].

Explanation to Table 4:

- In the case that a single library or data source is shown, recommended was a specific file in full, meaning that no merging is needed.
- If two sources are shown, different recommendations for slow and fast neutron regions were made, meaning that merging of 2 files is required.
- New-BNL. Atlas of Neutron Resonances [5] by Said Mughabhab, formerly known as BNL-325.
- SC (Said check). Reminder to S. Mughabghab to look into evaluations that were either not completed or a need for revision was indicated.
- EMPIRE. Evaluation using the nuclear reaction model code Empire [8] is recommended in the fast neutron region.
- Update needed. This refers to cases where ENDF/B-VII evaluations are not considered to be final.
- New library. This refers to ENDF/B-VII library, not yet released.
- New file. This refers to cases where entirely new file in the fast region will be created using the code EMPIRE.

Table 4. Summary recommendations for 211 existing and 7 new materials in the fission products range, Z = 31 – 68.

No	Z	Nuclide	Reviewer	Recommendation	Comment
1	31	31-Ga-69	Oblozinsky	New-BNL + JENDL-3.3	Merging needed
2		31-Ga-71	Oblozinsky	CENDL-3	
3	32	32-Ge-70	Herman	ENDF/B-VII	New library
4		32-Ge-72	Herman	ENDF/B-VII	New library
5		32-Ge-73	Herman	ENDF/B-VII	New library
6		32-Ge-74	Herman	ENDF/B-VII	New library
7		32-Ge-76	Herman	ENDF/B-VII	New library
8	33	33-As-75	Herman	New-BNL + JENDL-3.3	Merging needed
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	Merging needed
16	35	35-Br-79	Oblozinsky	JENDL-3.3	
17		35-Br-81	Oblozinsky	New-BNL + JENDL-3.3	Merging needed
18	36	36-Kr-78	Sirakov	New-BNL + JENDL-3.3	Merging needed
19		36-Kr-80	Sirakov	JENDL-3.3	
20		36-Kr-82	Sirakov	New-BNL + JENDL-3.3	Merging needed
21		36-Kr-83	Sirakov	CENDL-3	
22		36-Kr-84	Sirakov	New-BNL + JENDL-3.3, RRP up to 100 keV	Merging needed
23		36-Kr-85	Sirakov	JENDL-3.3 + EMPIRE	Merging needed
24		36-Kr-86	Sirakov	New-BNL + JENDL-3.3	Merging needed
25	37	37-Rb-85	Sirakov	JENDL-3.3	
26		37-Rb-86	Oblozinsky	ENDF/B-VI + EMPIRE	Merging needed
27		37-Rb-87	Sirakov	JENDL-3.3	
28	38	38-Sr-84	Shen	New-BNL + EMPIRE	Merging needed
29		38-Sr-86	Shen	New-BNL + JENDL-3.3	Merging needed

No	Z	Nuclide	Reviewer	Recommendation	Comment
30		38-Sr-87	Shen	JENDL-3.3	
31		38-Sr-88	Sirakov	New-BNL + CENDL-3	Merging needed
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		39-Y- 90	Shen	ENDF/B-VI + EMPIRE	New file
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	Merging needed
39		40-Zr-92	Chang	New-BNL + BROND-2	Merging needed
40		40-Zr-93	Chang	BROND-2 + JENDL-3.3	Merging needed
41		40-Zr-94	Chang	ENDF/B-VI + JENDL-3.3	Merging needed
42		40-Zr-95	Sirakov	JENDL-3.3	
43		40-Zr-96	Chang	New-BNL + JENDL-3.3	Merging needed
44	41	41-Nb-93	Shibata	JENDL-3.3 + ENDF/B-VI	Merging needed
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	Merging needed
49		42-Mo-95	Chang	ENDF/B-VII	New library
50		42-Mo-96	Chang	JENDL-3.3	
51		42-Mo-97	Chang	New-BNL + JENDL-3.3	Merging needed
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	Update needed
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	Merging needed
60		44-Ru-101	Nakagawa	ENDF/B-VII	New library
61		44-Ru-102	Nakagawa	New-BNL + CENDL-3	Merging needed
62		44-Ru-103	Nakagawa	New-BNL + CENDL-3	Merging needed

No	Z	Nuclide	Reviewer	Recommendation	Comment
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	Update needed
67		45-Rh-105	Shibata	ENDF/B-VI + CENDL-3	Merging needed
68	46	46-Pd-102	Herman	New-BNL + ENDF/B-VI	Merging needed
69		46-Pd-104	Shibata	New-BNL + ENDF/B-VI	Merging needed
70		46-Pd-105	Shibata	ENDF/B-VII	New library
71		46-Pd-106	Shibata	New-BNL + ENDF/B-VI	Merging needed
72		46-Pd-107	Shibata	JENDL-3.3	
73		46-Pd-108	Shibata	New-BNL + ENDF/B-VI	Merging needed
74		46-Pd-110	Shibata	New-BNL + ENDF/B-VI	Merging needed
75	47	47-Ag-107	Shen	New-BNL + JENDL-3.3	Merging needed
76		47-Ag-109	Shen	ENDF/B-VII	New library
77		47-Ag-110m	Shen	New-BNL + JENDL-3.3	Merging needed
78		47-Ag-111	Shen	ENDF/B-VI + EMPIRE	New file
79	48	48-Cd-106	Oblozinsky	New-BNL + JENDL-3.3	Merging needed
80		48-Cd-108	Oblozinsky	New-BNL + ENDF/B-VI	Merging needed
81		48-Cd-110	Herman	New-BNL + ENDF/B-VI	Merging needed
82		48-Cd-111	Herman	New-BNL + JENDL-3.3	Merging needed
83		48-Cd-112	Herman	New-BNL + ENDF/B-VI	Merging needed
84		48-Cd-113	Herman	New-BNL + CENDL-3	Merging needed
85		48-Cd-114	Herman	ENDF/B-VI	
86		48-Cd-115m	Oblozinsky	ENDF/B-VI + EMPIRE	New file
87		48-Cd-116	Oblozinsky	New-BNL + ENDF/B-VI	Merging needed
88	49	49-In-113	Zhuang	New-BNL + JENDL-3.3	Merging needed
89		49-In-115	Oblozinsky	New-BNL + JENDL-3.3	Merging needed
90	50	50-Sn-112	Shibata	New-BNL + JENDL-3.3	Merging needed
new		50-Sn-113	none	New-BNL + EMPIRE	New material
91		50-Sn-114	Shibata	New-BNL + JENDL-3.3	Merging needed
92		50-Sn-115	Shibata	New-BNL + JENDL-3.3	Merging needed
93		50-Sn-116	Shibata	New-BNL + JENDL-3.3	Merging needed
94		50-Sn-117	Shibata	New-BNL + JENDL-3.3	Merging needed

No	Z	Nuclide	Reviewer	Recommendation	Comment
95		50-Sn-118	Shibata	New-BNL + JENDL-3.3	Merging needed
96		50-Sn-119	Shibata	New-BNL + JENDL-3.3	Merging needed
97		50-Sn-120	Shibata	New-BNL + JENDL-3.3	Merging needed
98		50-Sn-122	Shibata	New-BNL + JENDL-3.3	Merging needed
99		50-Sn-123	Shibata	JENDL-3.3	
100		50-Sn-124	Shibata	New-BNL + JENDL-3.3	Merging needed
101		50-Sn-125	Shibata	ENDF/B-VI + EMPIRE	New file
102		50-Sn-126	Shibata	JENDL-3.3	
103	51	51-Sb-121	Shibata	New-BNL + CENDL-3	Merging needed
104		51-Sb-123	Shibata	New-BNL + CENDL-3	Merging needed
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	New file
108	52	52-Te-120	Zhuang	JENDL-3.3	
109		52-Te-122	Zhuang	New-BNL + JENDL-3.3	Merging needed
110		52-Te-123	Zhuang	New-BNL + JENDL-3.3	Merging needed
111		52-Te-124	Zhuang	New-BNL + JENDL-3.3	Merging needed
112		52-Te-125	Zhuang	New-BNL + JENDL-3.3	Merging needed
113		52-Te-126	Zhuang	New-BNL + JENDL-3.3	Merging needed
114		52-Te-127m	Zhuang	JENDL-3.3	
115		52-Te-128	Zhuang	New-BNL + JENDL-3.3	Merging needed
116		52-Te-129m	Zhuang	JENDL-3.3	
117		52-Te-130	Zhuang	New-BNL + CENDL-3	Merging needed
118		52-Te-132	Zhuang	ENDF/B-VI + EMPIRE	Merging needed
119	53	53-I- 127	Pronyaev	New-BNL + ENDF/B-VI	Merging needed
120		53-I- 129	Pronyaev	New-BNL + JENDL-3.3	Merging needed
121		53-I- 130	Herman	ENDF/B-VI + EMPIRE	New file
122		53-I- 131	Pronyaev	JENDL-3.3	
123		53-I- 135	Pronyaev	ENDF/B-VI + CENDL-3	Merging needed
124	54	54-Xe-123	Pronyaev	CENDL-3	
125		54-Xe-124	Pronyaev	New-BNL + CENDL-3	Merging needed
126		54-Xe-126	Pronyaev	New-BNL + JENDL-3.3	Merging needed
127		54-Xe-128	Zhuang	New-BNL + JENDL-3.3	Merging needed

No	Z	Nuclide	Reviewer	Recommendation	Comment
128		54-Xe-129	Pronyaev	New-BNL + JENDL-3.3	Merging needed
129		54-Xe-130	Zhuang	New-BNL + ENDF/B-VI	Merging needed
130		54-Xe-131	Shen	ENDF/B-VII	New library
131		54-Xe-132	Zhuang	New-BNL + CENDL-3	Merging needed
132		54-Xe-133	Zhuang	JENDL-3.3	
133		54-Xe-134	Zhuang	New-BNL + CENDL-3	Merging needed
134		54-Xe-135	Pronyaev	New-BNL + JENDL-3.3	Merging needed
135		54-Xe-136	Zhuang	New-BNL + CENDL-3	Merging needed
136	55	55-Cs-133	Sirakov	ENDF/B-VII	New library
137		55-Cs-134	Shen	New-BNL + JENDL-3.3	Merging needed
138		55-Cs-135	Sirakov	New-BNL + JENDL-3.3	Merging needed
139		55-Cs-136	Sirakov	SC + JENDL-3.3	SC: to be checked by Mughabghab
140		55-Cs-137	Sirakov	JENDL-3.3	
141	56	56-Ba-130	Oblozinsky	New-BNL + JENDL-3.3	Merging needed
142		56-Ba-132	Sirakov	New-BNL + JENDL-3.3	Merging needed
new		56-Ba-133	none	New-BNL + EMPIRE	New material
143		56-Ba-134	Pronyaev	New-BNL + JENDL-3.3	Merging needed
144		56-Ba-135	Pronyaev	New-BNL + JENDL-3.3	Merging needed
145		56-Ba-136	Pronyaev	New-BNL + JENDL-3.3	Merging needed
146		56-Ba-137	Pronyaev	New-BNL + JENDL-3.3	Merging needed
147		56-Ba-138	Pronyaev	New-BNL + CENDL-3	Merging needed
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	Merging needed
151		57-La-140	Nakagawa	ENDF/B-VI + EMPIRE	New file
152	58	58-Ce-136	Nakagawa	New-BNL + EMPIRE	New file
153		58-Ce-138	Nakagawa	New-BNL + EMPIRE	New file
new		58-Ce-139	none	New-BNL + EMPIRE	New material
154		58-Ce-140	Nakagawa	New-BNL + JENDL-3.3	Merging needed
155		58-Ce-141	Nakagawa	JENDL-3.3 (SC) + CENDL-3	SC: to be checked by Mughabghab
156		58-Ce-142	Nakagawa	New-BNL + JENDL-3.3	Merging needed
157		58-Ce-143	Nakagawa	ENDF/B-VI + EMPIRE	New file

No	Z	Nuclide	Reviewer	Recommendation	Comment
158		58-Ce-144	Nakagawa	JENDL-3.3	
159	59	59-Pr-141	Oblozinsky	ENDF/B-VII	New library
160		59-Pr-142	Oblozinsky	New-BNL + EMPIRE	New file
161		59-Pr-143	Oblozinsky	New-BNL + JENDL-3.3	Merging needed
162	60	60-Nd-142	Kawai	JENDL-3.3 (SC) + CENDL-3 (ENDF/B-VI for capture)	SC: to be checked by Mughabghab. Merge=3 sources.
163		60-Nd-143	Nakagawa	ENDF/B-VII	New library
164		60-Nd-144	Nakagawa	JENDL-3.3	
165		60-Nd-145	Kawai	ENDF/B-VII	New library
166		60-Nd-146	Nakagawa	New-BNL + CENDL-3 (JEFF-3.0 = inel, 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	Merging needed
170	61	61-Pm-147	Shen	New-BNL + JENDL-3.3	Merging needed
171		61-Pm-148	Shen	New-BNL + JENDL-3.3	Merging needed
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	Merging needed
176		62-Sm-147	Ignatyuk	ENDF/B-VII	New library
177		62-Sm-148	Ignatyuk	New-BNL + JENDL-3.3	Merging needed
178		62-Sm-149	Ignatyuk	ENDF/B-VII	New library
179		62-Sm-150	Ignatyuk	ENDF/B-VII	New library
180		62-Sm-151	Ignatyuk	ENDF/B-VII	New library
181		62-Sm-152	Ignatyuk	ENDF/B-VII	New library
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	Merging needed
185		63-Eu-152	Nakagawa	ENDF/B-VI (up to 10 keV) + JENDL-3.3	Merging may be complex
186		63-Eu-153	Ignatyuk	ENDF/B-VII	New library

No	Z	Nuclide	Reviewer	Recommendation	Comment
187		63-Eu-154	Ignatyuk	New-BNL + CENDL-3	Merging needed
188		63-Eu-155	Ignatyuk	JENDL-3.3 (SC) + CENDL-3	SC: to be checked by Mughabghab
189		63-Eu-156	Ignatyuk	JENDL-3.3	
190		63-Eu-157	Herman	ENDF/B-VI + EMPIRE	New file
191	64	64-Gd-152	Pronyaev	New-BNL + JENDL-3.3	Merging needed
new		64-Gd-153	none	New-BNL + EMPIRE	New material
192		64-Gd-154	Pronyaev	New-BNL + CENDL-3	Merging needed
193		64-Gd-155	Pronyaev	ENDF/B-VII	New library
194		64-Gd-156	Pronyaev	CENDL-3	
195		64-Gd-157	Pronyaev	ENDF/B-VII	New library
196		64-Gd-158	Pronyaev	New-BNL + CENDL-3	Merging needed
197		64-Gd-160	Pronyaev	New-BNL + CENDL-3	Merging needed
198	65	65-Tb-159	Pronyaev	New-BNL + JENDL-3.3	Merging needed
199		65-Tb-160	Shibata	New-BNL + EMPIRE	New file
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	New library
201		66-Dy-161	Shen	ENDF/B-VII	New library
202		66-Dy-162	Shen	ENDF/B-VII	New library
203		66-Dy-163	Shen	ENDF/B-VII	New library
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	Merging needed
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	Merging needed
209		68-Er-167	Chang	New-BNL + JENDL-3.3	Merging needed
210		68-Er-168	Chang	New-BNL + JENDL-3.3	Merging needed
211		68-Er-170	Chang	New-BNL + JENDL-3.3	Merging needed

5. Conclusions

SG21 performed a considerable job. In 3 years (2001 – 2004), the subgroup reviewed and assessed cross-sections for all 211 fission product materials currently available in 5 major evaluated libraries. All findings were examined by the concluding SG21 Workshop, which formulated final recommendations [6].

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 the 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 [5]. 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 [7].

It should be pointed out that SG21 deliverables were review reports and recommendations.

A follow-up WPEC Subgroup has already been established to produce actual data files, including testing. This is Subgroup 23 that has been approved by WPEC in May 2004. Expected outcome of SG23 should be international library of cross-section evaluations for fission products.

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3. S. Mughabghab, Thermal Neutron Capture Cross Sections, Resonance Integrals and g-Factors, Report INDC(NDS)-440 (International Atomic Energy Agency, Vienna, 2003)

4. Webpage of the WPEC Subgroup 21, www.nndc.bnl.gov/sg21.

5. S. Mughabghab, "Atlas of Neutron Cross Sections: Resonance Parameters and Thermal Cross Sections", under preparation, to be submitted to Elsevier by June 15, 2005, publication of the book (2 volumes) expected early 2006, see www.nndc.bnl.gov/atlas for more details.

6. P. Oblozinsky (editor), Minutes of the Workshop on Assessment of Fission Product Evaluations, Brookhaven National Laboratory, April 19 – 23, 2004, unpublished, see www.nndc.bnl.gov/sg21.

7. P. Oblozinsky (editor), Summary of the 54-th CSEWG Meeting, Nov 2-4, 2004, see www.nndc.bnl.gov/csewg.

8. M. Herman *et al*, Nuclear Reaction Model Code EMPIRE-2.19, www.nndc.bnl.gov/empire, released in March 2005.

APPENDIX A

Inter-comparison Plots For Ru-102

Figure 1. Ru-102 (n, total) cross sections

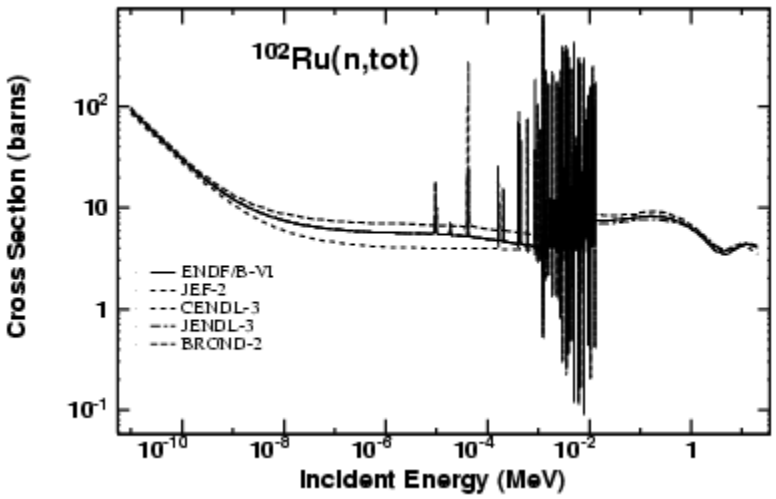


Figure 2. Ru-102 (n, total) cross sections in the fast neutron region

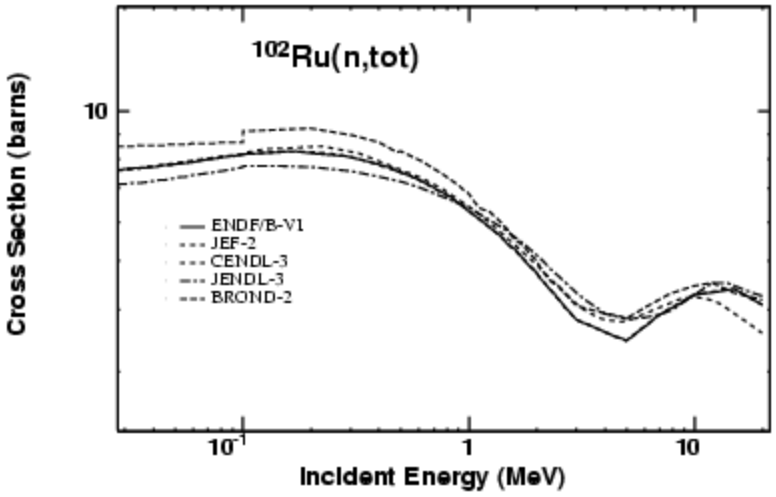


Figure 3. Ru-102 (n, gamma) cross sections

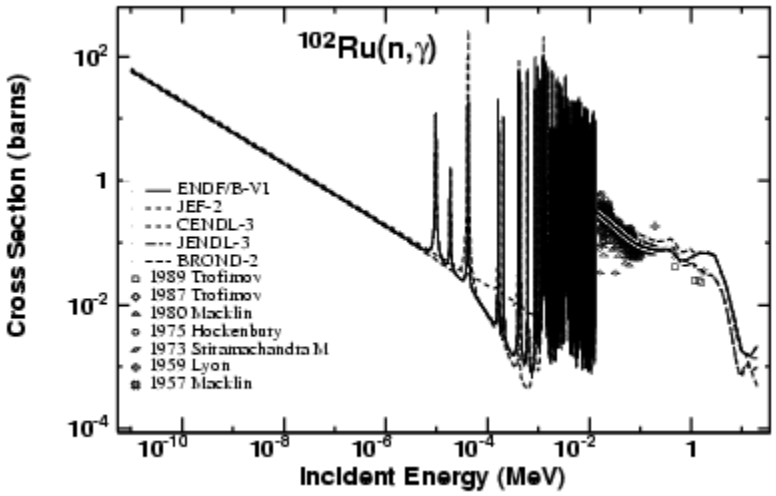


Figure 4. Ru-102 (n, gamma) cross sections in fast neutron region

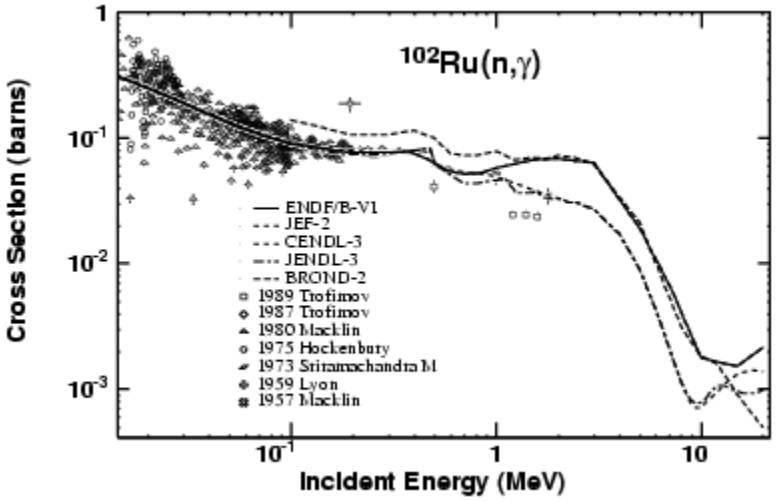


Figure 5. Ru-102 (n, elastic) cross sections

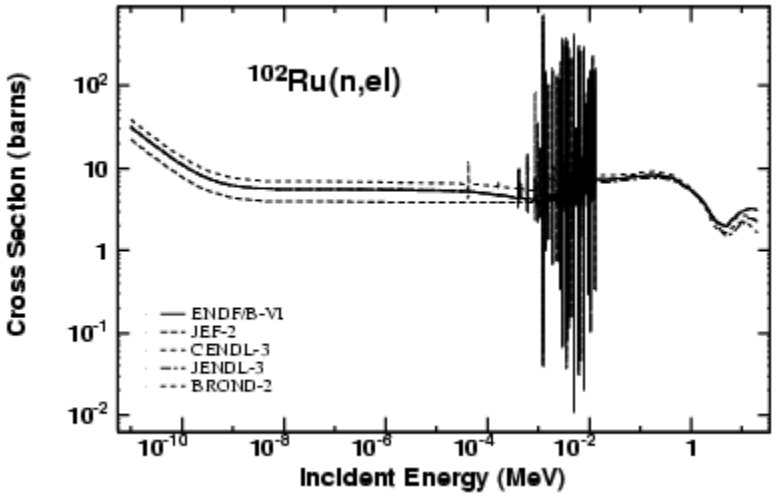


Figure 6. Ru-102 (n, inelastic) cross sections

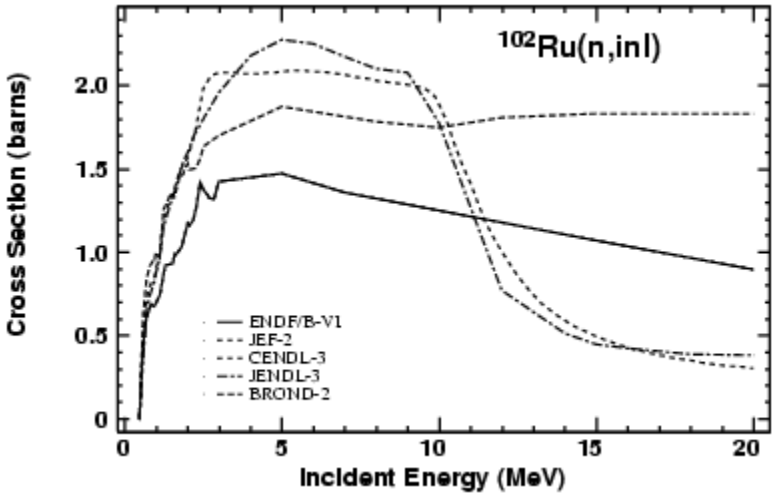


Figure 7. Ru-102 (n, 2n) cross sections

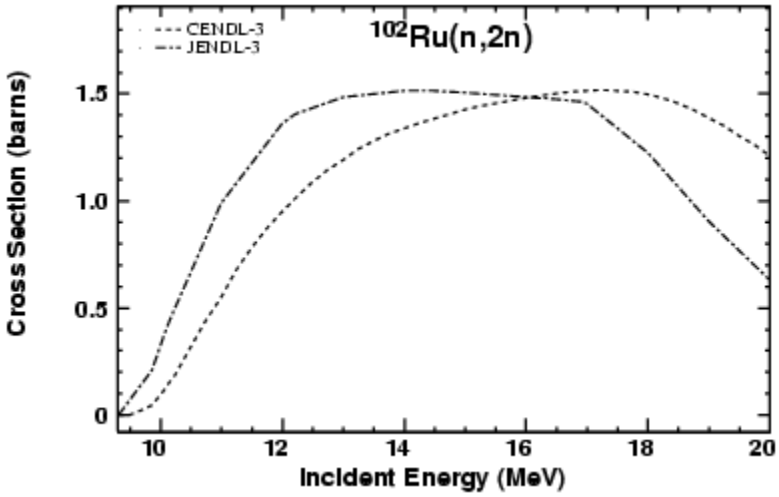


Figure 8. Ru-102 (n, p) cross sections

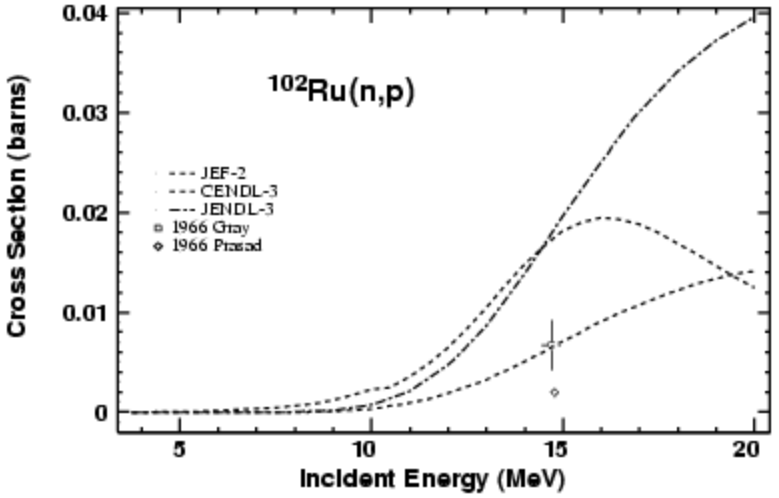
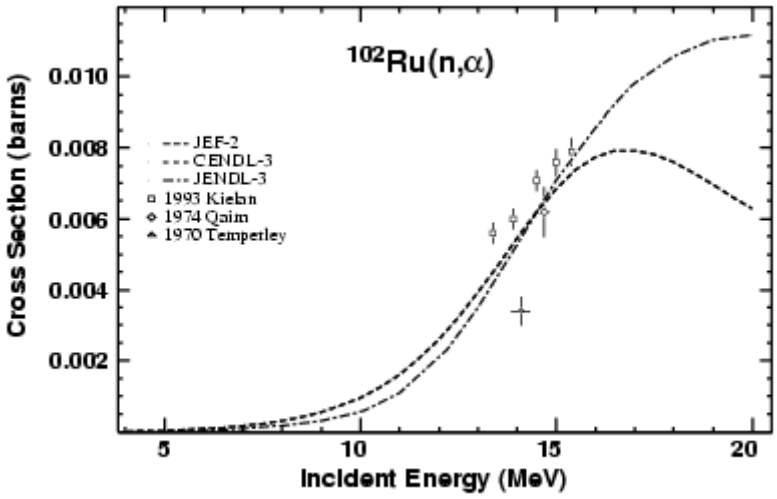


Figure 9. Ru-102 (n, alpha) cross sections



APPENDIX B

Review Report on Ru-102

Ru-102

Reviewed by T. Nakagawa, JAERI, February, 2002

1. Files

ENDF/B-VI: Evaluation was made in 1980 for ENDF/B-V. The results were the same as ENDF/B-IV. The resonance parameters were revised in 1992 for ENDF/B-VI.

JENDL-3.2: In 1984, the evaluation was made for JENDL-2. JENDL-2 data were revised in 1990 for JENDL-3.1. JENDL-3.2 is the same as JENDL-3.1.

JEF-2.2: ENDF/B-V was adopted. In 1989, the charged particle emission cross sections were adopted from REAC-ECN-4.

CENDL-3: Evaluation was performed in 1999. The data were compiled in 2001.

BROND-2: The evaluation was made in1984.

2. Thermal and resonance region

(1) Resolved resonance parameters

ENDF/B-VI (1.0e-5 eV – 13.4 keV)
The resolved resonance region is up to 13.4 keV. The parameters were determined on the basis of recommendation of Mughabghab et al. [Mu81], experimental data of Macklin and Halperin [Ma80], and Anufriev et al. [An85]. The levels between 1.7 and 2.66 keV were fictitious.

JENDL-3.2 (1.0e-5 eV – 13.4 keV)
The evaluation for JENDL-2 was based on the data of Priesmeyer and Jung [Pr72], Shaw et al. [Sh75], and Macklin and Halperin [Ma80]. Some levels below 2.6 keV are fictitious. They were revised by considering the data of Anufriev et al. [An85] for JENDL-3. Neutron widths of other levels were also modified.

JEF-2.2 (1.0e-5 eV – 1.61 keV)
Taken from ENDF/B-V. Only 3 resonance levels are given.

CENDL-3 (1.0e-5 eV – 13.4 keV)
ENDF/B-VI was adopted.

BROND-2 (1.0e-5 eV – 1.3 keV)
The recommendation of Mughabghab et al. [Mu81] was adopted.

(2) Unresolved resonance parameters

ENDF/B-VI (13.4 – 100 keV)
Determined so as to reproduce the average capture cross section measured by Macklin and Halperin [Ma80].

JENDL-3.2 (13.4 – 100 keV)
Determined so as to reproduce the capture and total cross section calculated with CASTHY code. This calculation is in good agreement with the capture cross section of Macklin and Halperin [Ma80]

JEF-2.2
No unresolved resonance parameters are given.

CENDL-3 (13.4 – 100 keV)
ENDF/B-VI was adopted.

BROND-2 (1.3 – 100 keV)
No information.

(3) Recommendation/conclusion for resonance region

The data of JEF-2.2 and BROND-2 are too old. The total and capture cross sections calculated from these two files are different from other evaluations, see Figs. a) and b). ***JENDL-3.2*** and ***ENDF/B-VI*** (***CENDL-3***) are of the same quality.

3. Fast neutron region

(1) Methodology

ENDF/B-VI
Theoretical calculation was widely used. The optical potential of Moldauer was adopted. Inelastic scattering was calculated with COMNUC-3 code, and the capture cross section with NCAP code. No direct inelastic was considered. No threshold reaction cross sections are given.

Legendre coefficients of elastically scattered neutrons were calculated from Moldauer potential. Isotropic distributions were given to the inelastic scattering.

Evaporation spectra were given to the continuum inelastic scattering.

JENDL-3.2
The total, elastic and inelastic scattering, and capture cross sections were calculated with the spherical optical model and statistical model code CASTHY. The gamma-ray strength function was determined so as to reproduce the capture cross section measured by Macklin et al. [Ma81, Ma79]. The 17 levels up to 2.4419 MeV were considered for the inelastic scattering. Direct inelastic scattering cross sections were calculated with DWUCK-4 to the first 2+ and 3– levels.

Other reaction cross sections were calculated with a pre-equilibrium and multi-step evaporation code PEGASUS. The (n,p) and (n,α) reaction cross sections were normalized to the systematics of Forrest [Fo86] at 14.5 MeV. Sum of the threshold reaction cross sections were considered as a competing reaction cross sections in the CASTHY calculation.

Angular distributions of elastic and inelastic scattering were calculated with CASTHY code, and those of direct inelastic with DWUCK-4 code. Isotropic distributions were assumed to the other reactions.

The energy distributions were calculated with PEGUSUS code.

JEF-2.2
ENDF/B-V and REAC-ECN-4 data were adopted.

CENDL-3
Calculated with SUNF code and DWUCK-4 code. The optical model parameters were determined with APMU code. The 6 levels up to 1.581 MeV were considered for the inelastic scattering.

Angular and energy distributions of neutrons were also calculated with SUNF code.

BROND-2
JENDL-1 was adopted in the energy region above 100 keV, except for the capture cross-section which was modified with the data of Belanova et al. [Be84] and direct capture cross section.

(2) Total cross section (MT=1)
Figs. 1, 2: http://www.nndc.bnl.gov/sg21/fp/nucl/ru102/ru102tot.htm

No experimental data are available for Ru-102 total cross section. Figure c) compares the evaluated data with the measured total cross section of natural Ru. From this figure, it is seen that ***CENDL-3*** reproduces well the experimental data.

(3) Capture cross section (MT=102)
Figs. 3, 4: http://www.nndc.bnl.gov/sg21/fp/nucl/ru102/ru102ng.htm

BROND-2 is too large above 100 keV. ***ENDF/B-VI*** is also too large above 1 MeV. ***JENDL-3.2*** and ***CENDL-3*** are in good agreement with available experimental data.

(4) Elastic scattering cross section (MT=2)
Fig. 5: http://www.nndc.bnl.gov/sg21/fp/nucl/ru102/ru102el.htm

This cross section was obtained as (total cross section) – (sum of partial cross sections) in the all libraries.

(5) Inelastic scattering cross section (MT=4, 51 – 91)
Fig. 6: http://www.nndc.bnl.gov/sg21/fp/nucl/ru102/ru102inl.htm

Excited levels considered in the files.
ENDF/B-VI 19 levels up to 2.814 MeV

JENDL-3.2	17 levels up to 2.442 MeV
JEF-2.2	19 levels up to 2.814 MeV
CENDL-3	6 levels up to 1.581 MeV
BROND-2	14 levels up to 2.372 MeV

The shape of total inelastic scattering cross section of ***ENDF/B-VI*** (***JEF-2.2***) and ***BROND-2*** is not reasonable. That of ***JENDL-3.2*** and ***CENDL-3*** is acceptable.

(6) (n,2n) reaction cross section (MT=16)

Fig. 7: http://www.nndc.bnl.gov/sg21/fp/nucl/ru102/ru102n2n.htm

JENDL-3.2 and ***CENDL-3*** give the (n,2n) reaction cross section. Their data are discrepant each other. However, no experimental data are available.

(7) (n,p) reaction cross section (MT=103)

Fig. 8: http://www.nndc.bnl.gov/sg21/fp/nucl/ru102/ru102np.htm

CENDL-3 reproduces well the data of Gray et al. [Gr66] at 14.7 MeV. However, thisexperimental data is the cross section of Tc-102m production. Therefore, real cross-section might be larger than CENDL-3. ***JENDL-3.2*** and ***JEF-2*** (REAC-ECN-4) were normalized to 16.7 mb at 14.5 MeV (Systematics of Forrest [Fo86]).

(8) (n,α) reaction cross section (MT=107)

Fig. 9: http://www.nndc.bnl.gov/sg21/nucl/ru102/ru102na.htm

CENDL-3 adopted the data of JEF-2.2. ***JEF-2.2*** was based on the data of REAC-ECN-4. ***JENDL-3.2*** was calculated with PEGASUS code and normalized to 6.2 mb at 14.5 MeV (Recommendation of Forrest [Fo86])

(9) Other reactions

The following other reaction cross sections are given in the files.

JENDL-3.2 (n,3n), (n,nα), (n,np), (n,d), (n,t)
CENDL-3 (n,3n), (n,nα), (n,np), (n,d), (n,t), (n,He-3)
JEF-2.2 (n,d), (n,t), (n,He-3), (n,2p)
ENDF/B-VI no
BROND-2 no

JENDL-3.2 dose not give the cross section of (n, He-3) and (n, 2p) because their cross sections calculated with PEGASUS code were smaller than 0.001 mb.

(10) Recommendation/conclusions for fast neutron region

JENDL-3.2 or ***CENDL-3*** is recommended. However, the total cross section of JENDL-3.2 is not in good agreement with experimental data. The number of levels for the inelastic scattering considered in CENDL-3 is too small.

References (Ru-102):

[Au85] Anufriev V.A. et al.: *Sov. At. Energy*, **58**, 328 (1985).
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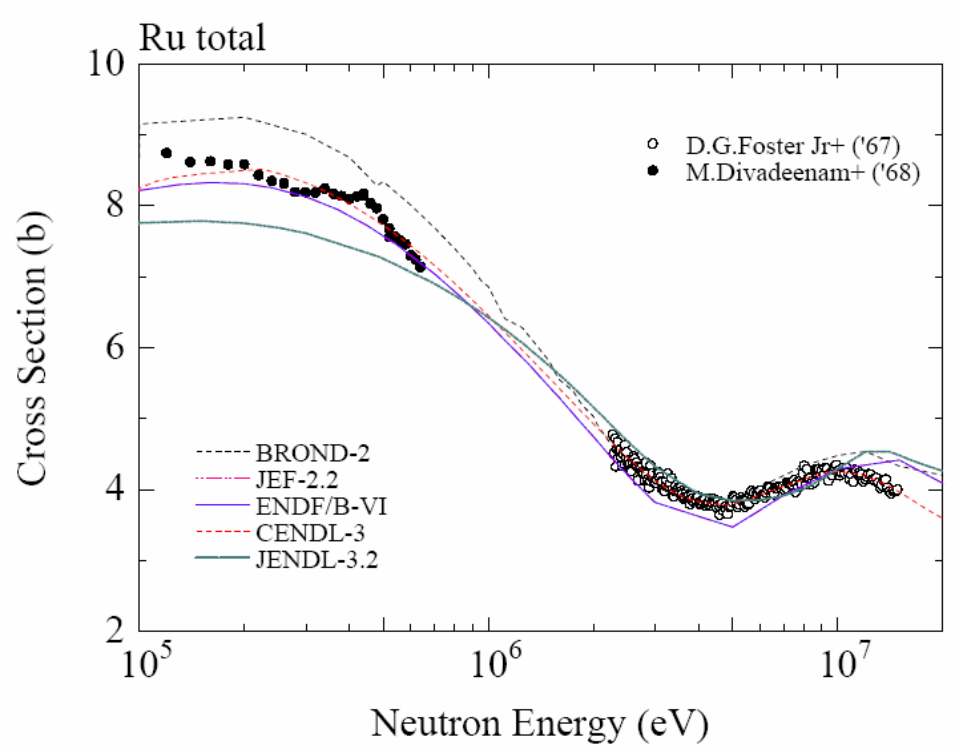
[Mu01] Mughabghab S.F.: *INDC(NDS)*-424, p.69 (2001)
[Mu81] Mughabghab S.F. et al.: "Neutron Cross Sections, Vol.1, Part A," Academic Press (1981).
[Pr72] Priesmeyer H.G. and Jung H.H.: *Atomkernenergie*, **19**, 111 (1972).
[Sh75] Shaw R.A. et al.: *Bull. Am. Phys. Soc.*, **20**, 560 (1975).
[Va72] Van der Linden R. et al.: *J. Radioanl. Chem.*, **11**, 133 (1972).

Figures (Ru-102):

Figures a), b) and c) were prepared by T. Nakagawa. Figures a) and b) are not shown here, while Figure c) is reproduced below. Figures 1 – 9, taken from inter-comparison plots [3], are shown in Appendix A.

Figure c. Ru-102 (n, total) cross-sections, evaluated data are compared with experimental data for natural Ru.



Tables (Ru-102):

Table 1. **Summary for Resolved and Unresolved Resonance Region: Ru-102.**

Library	RRP	URP	Remarks
ENDF/B-VI	13.4 keV MLBW	100 keV	
JENDL-3.2	13.4 keV MLBW	100 keV	
JEF-2.2	1.61 keV SLBW	no URP	Taken from ENDF/B-V
CENDL-3	13.4 keV MLBW	100 keV	Taken from ENDF/B-VI
BROND-2	1.3 keV MLBW	100 keV	Based on Mughabghab [Mu81]

Table 2. **Thermal Cross Sections and Resonance Integral: Ru-102.**

Library/Experiment	Total	Elastic	Capture	Res. Integral
ENDF/B-VI	6.794	5.565	1.228	4.33
JENDL-3.2	6.791	5.561	1.229	4.32
JEF-2.2	5.249	3.949	1.300	3.21
CENDL-3.2	6.794	5.565	1.228	4.29
BROND-2	8.075	6.899	1.176	6.30
Mughabghab [Mu81]			1.21±0.07	4.2±0.1
Mughabghab [Mu01]			1.21±0.07	
Lantz [La65]			1.23±10%*2	4.14±10%*4
Ishikawa [Is69]			1.37±0.132*2	
Van der Linden [Va72]				4.3±0.4
Heft [He78]			1.31±0.03*1	4.68±0.75
Anufriev et al. [Au85]*3	10.4±0.6			5.5±0.5

*1) Spectrum averaged
*2) Maxwellian averaged, activation
*3) Their data have been deleted from EXFOR file.
*4) Cut-off = 0.54 eV

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