

WPEC Subgroup 21
Assessment of Neutron Cross Sections for the Bulk of Fission Products

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Abstract

Since the last WPEC meeting, SG21 intended to review 100 of fission products evaluations. Reviewers were using information collected at the SG21 Web page, including interactive inter-comparison plots prepared for all 211 nuclei in the fission products range. As of today, 79 new reviews were completed, bringing the total to 98 since the start of the project in April 2001.

1. Introduction

Neutron cross sections of fission products (FPs) constitute a considerable part of the major evaluated nuclear data libraries. For example, in the recent release 8 of the US library ENDF/B-VI (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 325 materials included in the 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 the release 8 of the 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 the 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 fission products evaluations, including available experimental data as included in the EXFOR (CSISRS) library, and considering adopted evaluation methodology. This procedure is expected to yield reasonably good 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.

Since the last WPEC meeting in Geel, May 2002, the SG21 performed activities as described below.

2. SG21 Web Page

SG21 Web page, <http://www.nndc.bnl.gov/sg21>, has been maintained by BNL. Since April 2002, the following additions and updates were made:

- **SG21 Report to the WPEC Meeting 2002 (Geel, May, 2002).**
- **Minutes of the 2nd SG21 Meeting (Geel, May 24, 2002).**
- **Thermal Neutron Capture Cross Sections, Resonance Integrals and g-Factors.** This important report contains new re-evaluations by S. Mughabghab (BNL) [1]. Of particular importance are new thermal capture cross sections for elements and isotopes with atomic mass numbers $Z = 1-83$.
- **Deficiencies of Neutron Cross-Section Evaluated Files for Fission Products.** Summary of typical deficiencies, prepared by V. Pronyaev (IAEA Vienna), March 2003.
- **Priority List of Fission Products.** The list includes all 211 fission products. Denoted by colors are 130 priority fission products, see Final Report of the WPEC Subgroup 17, in particular Table 5.1 at pp. 28-30 [2]. That table provides one-group cross sections for capture in descending importance, determined by the product of the cross section and the yield of the nuclide. Remaining 81 FPs, not listed in Table 5.1 [2], are denoted in black.
- **One-group Capture Cross-Sections for 211 Fission Products.** These cross sections calculated I. Sirakov (BNL), for all 5 libraries consider by SG21, following the methodology used by SG17. On-group cross sections represent capture cross section averaged over the fast neutron spectrum as used by SG17.
- **Set of Reviews (18 FPs in 2000/2001 and 79 in 2002/2003).** This part provides links to all reviews prepared by reviewers of SG21.

3. Review Procedures

Procedures were established in the first year of the project using experience of 10 reviewers who made trial reviews of 18 fission products evaluations. In particular, it was agreed that one should proceed along 4 steps:

1. **Initial analysis.** Check all evaluations, check EXFOR data for completeness and correctness, inspect inter-comparison plots.
2. **Thermal and resonance region.**
 - Analyze thermal cross sections (total, capture, elastic).

- Analyze resolved resonance & unresolved resonance region (total, capture, elastic).
- Consider recent values by S. Mughabghab [1] and one-group capture cross sections.

3. Fast energy region.

- Analyze total, capture, elastic, inelastic, (n,2n), (n,p) and (n, α) cross sections.
- Analyze evaluation methodology, consider year of origin and reputation of evaluator, and consider physics along with codes and parameters as well as completeness of evaluation.

4. **Report.** Write report, list findings, state recommendation for the best evaluation or any other conclusion as appropriate.

An important tool for reviewers was provided by the graphical inter-comparison for all 211 fission products, developed by V. Zerkin (IAEA, Vienna), <http://www.nndc.bnl.gov/sg21/fp21/>. The plots compare data from 5 evaluated libraries and from EXFOR 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 are provided for total and capture cross sections. This makes altogether 9 plots per nucleus, totaling to almost 1,900 plots in the whole package. Convenient access to evaluated files as well as to EXFOR files is readily available. This allows reviewer an easy cross communication with evaluated and experimental information.

4. Reviews and Assessment

The list of 100 fission products evaluations planned to be reviewed in the period of May 2002 – April 2003 is given in Table 1. In creation of this list, priority was given to nuclei identified as priority by the WPEC SG17, chaired by H. Gruppelaar [2], that examined status of pseudo-fission-product cross-sections for fast reactors. As of today, 79 evaluations out of planned 100 were reviewed.

Table 1. List of 100 fission products planned to be reviewed during May 2002 – April 2003. Denoted in bold are 79 nuclei reviewed by April 17, 2003.

Reviewer	1	2	3	4	5	6	7	8	9	10	
Oblozinsky	Br-81	In-115	Cd-110	Cd-111	Cd-112	Cd-113	Cd-114	Cd-116	Pr-141	Pr-143	7
Sirakov	Kr-84	Kr-85	Kr-86	Rb-85	Rb-87	Cs-133	Cs-135	Cs-136	Cs-137	Ba-140	7
Chang	Zr-91	Zr-92	Zr-93	Zr-94	Zr-96	Mo-95	Mo-96	Mo-98	Mo-99	Mo-100	10
Nakagawa	Ru-100	Ru-101	Ru-103	Ru-104	Ru-106	Ce-140	Ce-141	Ce-142	Ce-143	La-139	10
Shibata	Rh-103	Rh-105	Pd-104	Pd-105	Pd-106	Pd-107	Pd-110	Sn-124	Sn-125	Sn-126	10
Kawai	Nb-95	Sb-121	Sb-123	Nd-143	Nd-144	Nd-145	Nd-146	Nd-147	Nd-148	Nd-150	5
Ignatyuk	Sm-147	Sm-148	Sm-149	Sm-150	Sm-151	Sm-154	Eu-153	Eu-154	Eu-155	Eu-156	0
Pronyaev	I-127	I-129	I-131	Tb-159	Gd-154	Gd-155	Gd-156	Gd-157	Gd-158	Gd-160	10
Shen	Y-89	Y-91	Ag-109	Ag-111	Pm-147	Pm-148	Pm-149	Dy-160	Dy-161	Dy-162	10
Zhuang	Te-125	Te-127m	Te-128	Te-129m	Te-130	Xe-128	Xe-130	Xe-133	Xe-134	Xe-136	10
Total											79

A complete set of reviews is available on the SG21 Web site. It includes 18 reviews completed in the 1st year of the project, and another 79 completed in the 2nd year of the project, see http://www.nndc.bnl.gov/sg21/rev/rev_list.htm.

A convenient list of reviews is provided in Table 2. This table lists all 211 fission products, denotes by colors 130 priority fission products, and indicates 18+79 = 98 of those that were already reviewed. The priority list follows the Report NEA/WPEC-17 (Table 5.1 at pp.28-30) [2] that provides one-group cross sections for capture in descending importance, determined by the product of the capture cross section and the yield of the nuclide.

Table 2. List of 211 fission products marked according to their priority for fast reactor applications and showing the status of reviews. Notation: Underline - already reviewed (98 nuclides), **red** - first 40 nuclides (p. 28 of SG17 report), **blue** - next 45 nuclides (p. 29 of SG17 report) and **green** - last 45 nuclides (p. 30 of SG17 report).

31-Ga-	<u>69</u> , 71
32-Ge-	70, 72, 73, 74, 76
33-As-	75
34-Se-	74, 76, <u>77</u> , <u>78</u> , 79, <u>80</u> , <u>82</u>
35-Br-	79, <u>81</u>
36-Kr-	78, 80, 82, <u>83</u> , <u>84</u> , <u>85</u> , <u>86</u>
37-Rb-	<u>85</u> , 86, <u>87</u>
38-Sr-	84, 86, 87, <u>88</u> , <u>89</u> , 90
39-Y -	<u>89</u> , 90, <u>91</u>
40-Zr-	90, <u>91</u> , <u>92</u> , <u>93</u> , <u>94</u> , <u>95</u> , <u>96</u>
41-Nb-	93, 94, <u>95</u>
42-Mo-	92, 94, <u>95</u> , <u>96</u> , <u>97</u> , <u>98</u> , <u>99</u> , <u>100</u>
43-Tc-	<u>99</u>
44-Ru-	96, 98, 99, <u>100</u> , <u>101</u> , <u>102</u> , <u>103</u> , <u>104</u> , 105, <u>106</u>
45-Rh-	<u>103</u> , <u>105</u>
46-Pd-	102, <u>104</u> , <u>105</u> , <u>106</u> , <u>107</u> , <u>108</u> , <u>110</u>
47-Ag-	107, <u>109</u> , 110m, <u>111</u>
48-Cd-	106, 108, <u>110</u> , <u>111</u> , <u>112</u> , <u>113</u> , <u>114</u> , 115m, <u>116</u>
49-In-	113, <u>115</u>
50-Sn-	<u>112</u> , 114, 115, 116, <u>117</u> , <u>118</u> , <u>119</u> , <u>120</u> , 122, <u>123</u> , <u>124</u> , <u>125</u> , <u>126</u>
51-Sb-	<u>121</u> , <u>123</u> , 124, <u>125</u> , 126
52-Te-	120, 122, 123, 124, <u>125</u> , 126, <u>127m</u> , <u>128</u> , <u>129m</u> , <u>130</u> , 132
53-I -	<u>127</u> , <u>129</u> , 130, <u>131</u> , <u>135</u>
54-Xe-	123, 124, 126, <u>128</u> , 129, <u>130</u> , <u>131</u> , <u>132</u> , <u>133</u> , <u>134</u> , 135, <u>136</u>
55-Cs-	<u>133</u> , 134, <u>135</u> , <u>136</u> , <u>137</u>
56-Ba-	<u>130</u> , <u>132</u> , <u>134</u> , 135, <u>136</u> , <u>137</u> , <u>138</u> , <u>140</u>
57-La-	138, <u>139</u> , <u>140</u>
58-Ce-	136, 138, <u>140</u> , <u>141</u> , <u>142</u> , <u>143</u> , <u>144</u>
59-Pr-	<u>141</u> , 142, <u>143</u>

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](#), [154](#), [155](#), [156](#), [157](#), [158](#), [160](#)
65-Tb-[159](#), [160](#)
66-Dy-[160](#), [161](#), [162](#), [163](#), [164](#)
67-Ho-165
68-Er-162, [164](#), [166](#), [167](#), [168](#), [170](#)

Reviews differ in detail and thoroughness of arguments given. Examples of detailed reviews by members of 4 teams of SG21 would be, see http://www.nndc.bnl.gov/sg21/rev/rev_list.htm,

- I. Sirakov (ENDF/B team) ^{133}Cs ,
- K. Shibata (JENDL team) ^{103}Rh ,
- V. Pronyaev (BROND team) ^{129}I ,
- Shen Qingbiao (CENDL team) ^{161}Dy .

In most cases, the recent evaluations by JENDL-3 and less frequently by CENDL-3 were recommended. Recommendations are summarized in Table 3.

Table 3. Summary of recommendations for 18 + 79 reviewed fission products.

This table will be prepared later.

References

1. S.F. Mugahabghab, Thermal neutron capture cross sections, resonance integrals and g-Factors, Report INDC (NDS)-440 (IAEA, Vienna, February 2003).
2. H. Gruppelaar et al, Status of pseudo-fission-product cross-sections for fast reactors, Final Report of the Subgroup 17, NEW/WPEC-17, ECN-R-98-014 (NEA, Paris 1998).