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Evaluated Data Library for the Bulk of Fission Products

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

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Foreword

The Working Party on International Nuclear Data Evaluation Co-operation (WPEC) was established under the aegis 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 WPEC 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 organised through the Nuclear Data Section of the International Atomic Energy Agency (IAEA).

The following report has been issued by WPEC Subgroup 23, whose mission was to produce an international library of neutron cross-section evaluations for the bulk of fission products. This activity was a follow-up to that of WPEC Subgroup 21, which reviewed and assessed data in all major evaluated data libraries and provided recommendations for the best evaluations for all available fission products. Following these recommendations, WPEC Subgroup 23 created the actual library containing 219 fission product materials, made additional improvements and performed data validation for a limited set of materials.

The opinions expressed in this report are those of the authors only and do not necessarily represent the position of any member country or international organisation.

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Summary

Subgroup 23 has produced the International Library of Neutron Cross-section Evaluations for the Bulk of Fission Products. This SG23 library contains evaluations for a complete set of 219 materials in the fission products range based on the best data available in major evaluated nuclear data libraries. The selection of these evaluations followed recommendations completed by Subgroup 21 in 2004. In addition to these recommendations, Subgroup 23 took into consideration the latest evaluations finalised in the period of 2005-2006 for the then-forthcoming ENDF/B-VII.0 library.

Review and assessment of fission product evaluations of all materials with Z = 31-68 as done by Subgroup 21 considered data from all evaluated libraries available in 2004, namely, ENDF/B-VI.8, JENDL-3.3, JEFF-3.0, BROND-2.2 and CENDL-3.0. By also taking into consideration the latest ENDF/B-VII.0 evaluations completed in 2006, Subgroup 23 ensured that the SG23 library was based on the best evaluations available. The fifth edition of the well-known BNL-325 by S.F. Mughabghab was published in 2006 with the title *Atlas of Neutron Resonances*, and these latest thermal and resonance data were also taken into account.

The SG23 library was subject to data verification which consisted of checking with a suite of ENDF-6 checking codes, followed by processing with NJOY-99 and completed by test runs with the Monte Carlo code MCNP5 to ensure that a processed library suitable for neutronics calculations can be produced. Basic validation of the library complemented with detailed benchmarking for a dozen of the most important fission products has also been done. Although the library generally performs well, the detailed benchmarking revealed a need for further improvements as concerns priority fission products.

The library was given the internationally recognised number NLIB=21 and has been adopted in full by the ENDF/B-VII.0 library released in December 2006. Most recently 152 materials have been adopted by the RUSFOND library.

Introduction

Subgroup 23 (SG23) was established by the Working Party on International Evaluation Co-operation (WPEC) in the fall of 2004 as a follow-up to Subgroup 21. SG23 has thus become the third WPEC project devoted to neutron cross-sections of fission products. Several years earlier, H. Gruppelaar, *et al.* completed work under Subgroup 17 on the *Status of Pseudo-fission-product Cross-sections for Fast Reactors* (NEA, 1998). The results of SG17 partly guided the work of SG21, which completed its mission in spring 2004 and produced recommendations on the best neutron cross-section evaluations for fission products (NEA, 2005).

Neutron cross-sections of fission products (FP) constitute a considerable part of every major evaluated nuclear data library. For instance, the United States' ENDF/B-VI.8 library released in October 2001 contains 196 materials that fall into the range of fission products broadly defined as materials with Z = 31-68. This large number of fission product materials should be compared with the total of 328 materials included in ENDF/B-VI.8.

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 the ENDF/B-VI library conducted by R.Q. Wright and R.E. MacFarlane (2000) revealed the following:

- About 65% of the evaluations were performed some 30 years ago, that is, almost 40 years ago as of the present.
- About 55% of the evaluations have unphysical isotropic neutron elastic angular distribution.
- About 30% of the evaluations use outdated point-wise representation for cross-sections in the neutron resonance region.
- About 30% of the evaluations use outdated single-level Breit-Wigner representation for neutron resonances in the resolved resonance region.

To address these issues, the WPEC established SG21 in 2001. 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. It was deemed to be insufficient for the most important fission products (20-40 nuclides, depending on the application), for which validation methods should be adopted to guide the selection process.

A logical follow-up to SG21 was the creation of Subgroup 23 in fall 2004. This new subgroup has been charged to build upon the results of SG21 and produce an actual neutron cross-section data library for the bulk of fission products. This is the subject of the present report. We first briefly discuss SG21 recommendations and then describe how the SG23 library has been created. This is followed by SG23 validation. A full list of the materials studied by SG23 and some details about related files can be found in the Appendix.

Summary of SG21 recommendations

Subgroup 21 performed review and assessment of neutron cross-sections for fission products by looking into all available evaluations. Evaluated nuclear data libraries of five major efforts were considered, namely the United States (ENDF/B-VI.8 and preliminary ENDF/B-VII.0), Japan (JENDL-3.3, released in 2002), Europe (JEFF-3.0, released in 2000), Russia (BROND-2.2, released in 1992) and China (CENDL-3.0, made available for SG21 in 2001).

The SG21 review was undertaken as follows. Intercomparison plots of evaluated data in these five libraries were prepared for the most important reaction channels along with a comparison from the experimental reaction database EXFOR, totalling 1 900 plots. SG21 included ten active reviewers from Brookhaven, JAERI Tokai-mura, IPPE Obninsk as well as KAERI Daejon and CNDC Beijing. This made it possible to review each material individually within the relatively short period of two years. The low-energy region (thermal point, resonances), and the fast neutron region for each material were reviewed separately. A review report for each material was written that described the review procedure, an analysis of the evaluation methodology, comparisons with recent data, and summarised findings and recommendations of the best evaluation separately for the low-energy and the fast neutron regions.

These reviews were discussed at the workshop held at BNL in April 2004, and final recommendations were made for the best evaluation for each material. A detailed account can be found in the SG21 final report (NEA, 2005).

Subsequently, the SG21 recommendations were reviewed by the new SG23 team in 2005 by taking into account a considerably increased number of new evaluations produced for the forthcoming United States library ENDF/B-VII.0 (Chadwick, 2006). New evaluations were mostly due to new BNL resonance data from the *Atlas of Neutron Resonances* (Mughabghab, 2006) combined with new BNL evaluations in the fast neutron region. In addition, many new resonance evaluations from the *Atlas of Neutron Resonances* were combined with non-US evaluations in the fast neutron region.

A summary of final selection is given in Table 1. A detailed list of 219 materials in the fission product range (Z = 31-68) is given in the Appendix along with the explicit list of evaluations selected from major evaluated libraries.

Table 1: Summary of selected evaluations for 219 fission products based on SG21 recommendations and later updates

Full files were adopted for 135 materials, files for 84 materials were merged from different evaluations

Library (data source)	Full file	Resonance region	Fast region
ENDF/B-VI.8, released in 2001	1	3	13
New evaluations for ENDF/B-VII.0	74	74	–
JEFF-3.1, released in 2005	1	–	–
JENDL-3.3, released in 2002	47	7	56
CENDL-3.0, released in 2001	11	–	15
BROND-2.2, released in 1992	1	–	–
Total number of materials	**135**	**84**	**84**

New fission product evaluations

New evaluations for 74 materials produced for the US ENDF/B-VII.0 library were taken into consideration and as a rule they were included into SG23 selected files. These evaluations were produced by the following laboratories:

- 32 materials evaluated through a BNL-KAERI collaboration (Korea);
- 5 materials evaluated through a BNL-JAERI collaboration (Japan);
- 12 materials evaluated by BNL in collaboration with other US national laboratories (LANL, LLNL and ORNL);
- 25 low priority materials by BNL with the assistance of B. Sarer (Turkey).

These new evaluations used the BNL evaluation methodology based on the combined use of *Atlas of Neutron Resonances* (Mughabghab, 2006) and the nuclear reaction model code EMPIRE in the fast neutron region. This methodology was consolidated into the extended EMPIRE code described in various places, the most recent reference being an extensive paper in *Nuclear Data Sheets* (Herman, 2007).

In the thermal, resolved resonance region (RRR) and unresolved resonance region (URR) the evaluations are based on the Mughabghab new *Atlas of Neutron Resonances* (2006), which employed the multi-level Breit-Wigner representation except for in the URR, where the single-level Breit-Wigner representation is used. Resonance parameters of observed resonances were combined with those placed below the neutron binding energy (negative-energy resonances or bound levels) to reproduce thermal cross-sections.

Evaluations in the fast neutron energy region were based on the nuclear reaction model code system EMPIRE developed by Herman *et al*. (2007). This code couples a set of nuclear reaction models and databases as well as an extensive set of utility codes that facilitate the evaluations process.

EMPIRE is a modular system of nuclear reaction codes, comprising various nuclear reaction models and designed for calculations over a broad range of energies. The energy range extends from the beginning of the unresolved resonance region (~ keV range) up to 20 MeV and above. The code accounts for the major nuclear reaction mechanisms, including direct, pre-equilibrium and statistical (compound nucleus) processes. Use is made of the optical model including the coupled-channel approach, covering both spherical and deformed nuclei. The results can be converted into an ENDF-6 formatted file using the accompanying code EMPEND and completed with neutron resonances that can be either extracted from the existing evaluations or supplied by one's own evaluation based on the *Atlas of Neutron Resonances*. The package contains the full EXFOR (CSISRS) library of experimental reaction data that are automatically retrieved during the calculations. Publication-quality graphs can be obtained using the powerful and flexible plotting package ZVView. The graphical user interface, written in Tcl/Tk, provides for easy operation of the system.

All new evaluations include the full set of reaction channels relevant for neutronics calculations, and angular distributions, energy-angle correlated spectra and photon production are always provided.

Priority materials

New evaluations were performed for materials considered to be priority fission products. These are 19 materials based on the analysis by Dehart (1995), namely:

- ^{95}Mo, ^{99}Tc, ^{101}Ru, ^{103}Rh, ^{105}Pd, ^{109}Ag, ^{131}Xe, ^{133}Cs, ^{141}Pr, ^{153}Eu;
- ^{143,145}Nd, ^{147,149,150,151,152}Sm, ^{155,157}Gd.

A flavour of these new evaluations is given below. We first briefly discuss ten materials individually. The evaluations of the remaining nine priority fission product materials (^{143,145}Nd, ^{147,149,150,151,152}Sm and ^{155,157}Gd) are discussed in the following subsection.

^{95}Mo

This is an important fission product and neutron absorber. A new evaluation was performed by Kim, *et al.* (2007). In the low-energy region (thermal, RRR and URR) it updates an earlier evaluation by Oh, Chang and Mughabghab (2000) that was included in the ENDF/B-VI.8 library. In the fast neutron region it represents a completely new evaluation. In Figure 1 we show total cross-sections for ^{95}Mo, illustrating improvement over other evaluated libraries, most notably over ENDF/B-VI.8 which displays a considerable mismatch between the resonance and the fast neutron regions.

^{99}Tc

This long-lived radioactive nuclide, with a half-life of 2.1×10^5 years, is of top importance for nuclear waste management and waste transmutation applications. A new evaluation was performed by Rochman, *et al.* (2008). Importantly, the thermal capture cross-section was fixed to reproduce the latest value of 22.8 b (Mughabghab, 2006) as shown in Figure 2. Overall improvement for capture can be seen in Figure 3.

^{101}Ru

The new evaluation was performed by Kim, *et al.* (2007). In the low-energy region it updates an earlier evaluation by Oh, Chang and Mughabghab (2000) that was included in the ENDF/B-VI.8 library. In the fast neutron region it represents a completely new evaluation.

^{103}Rh

This is an important fission product and neutron absorber. The new evaluation was performed by Kim, *et al.* (2000), which replaced the 1974 evaluation in ENDF/B-VI.8. Figure 4 shows neutron inelastic cross-sections and demonstrates excellent agreement with (n,n′) isomeric state production, thereby building confidence in the evaluated total (n,n′) cross-sections.

^{105}Pd

The new evaluation was performed by Kim, *et al.* (2000). In the low-energy region it updates an earlier evaluation by Oh, Chang and Mughabghab (2000) included in the ENDF/B-VI.8 library. In the fast neutron region it represents a completely new evaluation.

^{109}Ag

The new evaluation was performed by Kim, *et al.* (2007). In the low-energy region it updates an earlier evaluation by Oh, Chang and Mughabghab (2000) included in the ENDF/B-VI.8 library. In the fast neutron region it represents a completely new evaluation.

^{131}Xe

The new evaluation was performed by Kim, *et al.* (2007). In the low-energy region it updates an earlier evaluation by Oh, Chang and Mughabghab (2000) included in the ENDF/B-VI.8 library. In the fast neutron region it represents a completely new evaluation.

^{133}Cs

The new evaluation was performed by Kim, *et al.* (2007). In the low-energy region it updates an earlier evaluation by Oh, Chang and Mughabghab (2000) included in the ENDF/B-VI.8 library. In the fast neutron region it represents a completely new evaluation.

^{141}Pr

The new evaluation was performed by Kim, *et al.* (2007). In the low-energy region it updates an earlier evaluation by Oh, Chang and Mughabghab (2000) included in the ENDF/B-VI.8 library. In the fast neutron region it represents a completely new evaluation.

^{153}Eu

The new evaluation was performed by Obložinský, *et al.* in 2002 and updated in 2006. In the low-energy region this evaluation is completely new. In the fast neutron region it represents a new evaluation facilitated by an excellent coupled-channel optical model potential developed earlier by P.G. Young (1987).

Figure 1: ^{95}Mo(n,tot) cross-sections compared with experimental data and other evaluated data libraries

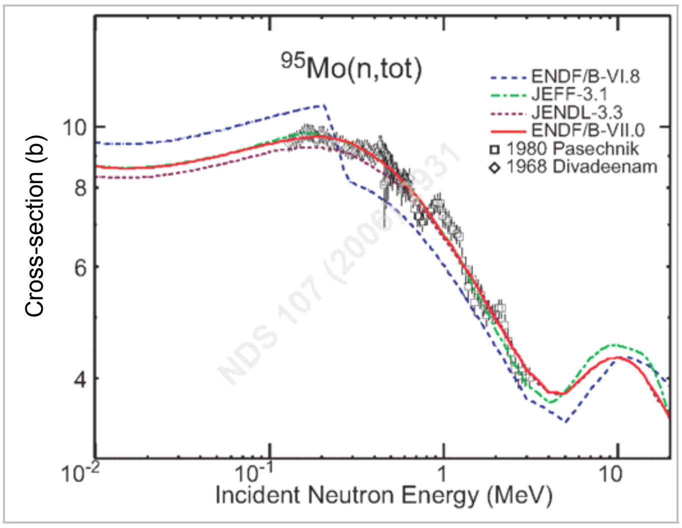


Figure 2: ^{99}Tc(n,γ) at low energies compared with data and other evaluated libraries

Thermal point was adjusted to reproduce the latest value of 22.8 b (Mughabghab, 2006)

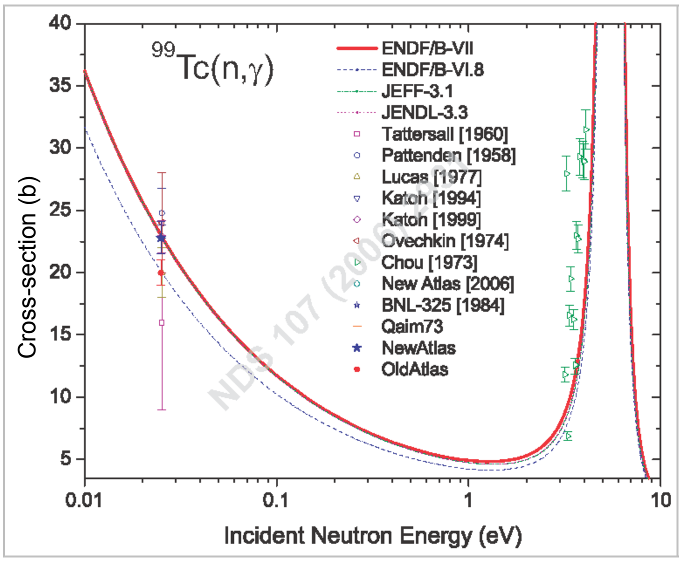


Figure 3: ^{99}Tc(n,γ) cross-sections in the unresolved resonance energy range compared with data and other evaluated data libraries

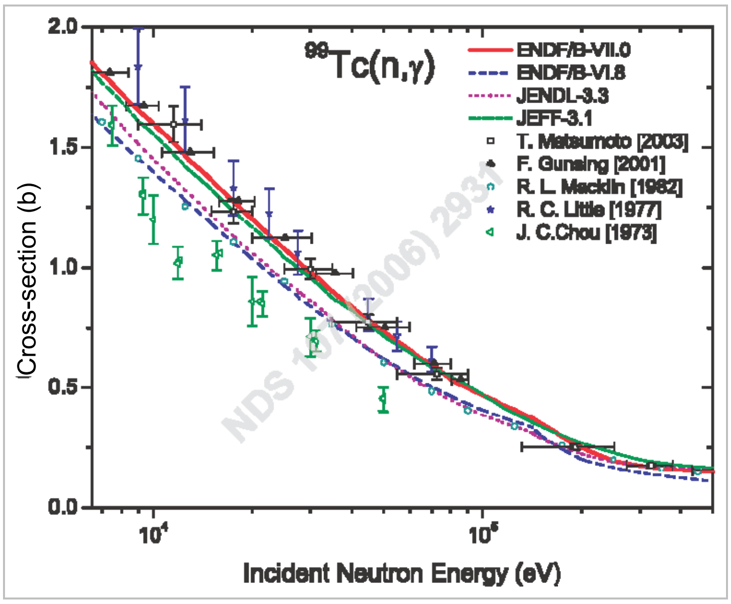
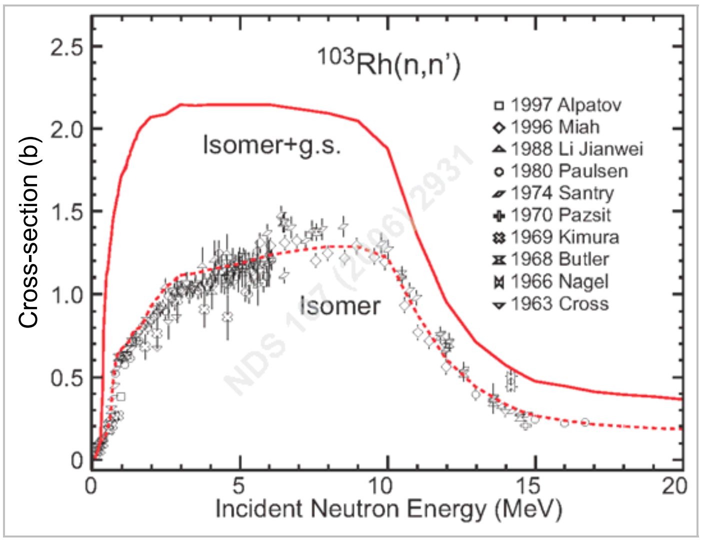


Figure 4: ^{103}Rh(n,n′) compared with data available for the isomeric state production



Complete isotopic chains

Simultaneous evaluation of the complete isotopic chain for a given element represents a modern approach toward undertaking evaluations. This advanced method became possible due to tremendous progress in the development of evaluation tools in recent years. In particular, the combined capabilities of the *Atlas of Neutron Resonances*, the nuclear reaction model code EMPIRE, input parameter libraries such as RIPL (the latest version of which is RIPL-3), the experimental cross-section library EXFOR and numerous ENDF-6 formatting and checking utility codes has facilitated an extremely complex evaluation task. A considerable advantage of this approach is a full and consistent utilisation of data that are often measured on natural elements rather than isotopes, a consistent application of model parameters, and comparison with data by summing up isotopic evaluations into a single elemental representation. This methodology was applied to five elements, Ge, Nd, Sm, Gd and Dy, totalling 37 materials (Ge = 5 isotopes, Nd = 8 isotopes, Sm = 9 isotopes, Gd = 8 isotopes and Dy = 7 isotopes).

Nd isotopes

A set of neodymium evaluations includes two priority fission products, ^{143,145}Nd, another five stable isotopes and the radioactive ^{147}Nd. Neodymium is one of the most reactive rare-earth metals. It is important in nuclear reactor engineering as a fission product which absorbs neutrons in a reactor core. A new evaluation was performed by Kim, *et al*. (2008). Shown in Figure 5 are evaluated total neutron cross-sections compared with experimental data on all Nd isotopic samples [including high-quality data by Wisshak (1997)] as well as on elemental samples. Capture cross-sections are compared with data in Figure 6.

Sm isotopes

A complete set of samarium isotopes includes five priority fission products, ^{147,149,150,151,152}Sm isotopes, another two naturally occurring isotopes, and the radioactive ^{151,153}Sm. With its high absorption cross-sections for thermal neutrons, samarium is an important material for nuclear reactor control rods and for neutron shielding. New evaluations were performed by Kim, *et al.* (2007). Figure 7 displays (n,2n) cross-sections on all Sm isotopes, compared to available data.

Gd isotopes

A complete isotopic chain for gadolinium includes two priority fission products, ^{155,157}Gd, another five stable isotopes, and the long-lived radioactive ^{153}Gd. Gadolinium has extremely high capture cross-sections for thermal neutrons and is of significant importance for nuclear criticality safety applications. New evaluations were performed, including the resolved resonance region, unresolved resonance and fast neutron region (Chadwick, 2006), see Figure 8 for capture.

Figure 5: Evaluated total cross-sections for eight isotopes of Nd compared with data

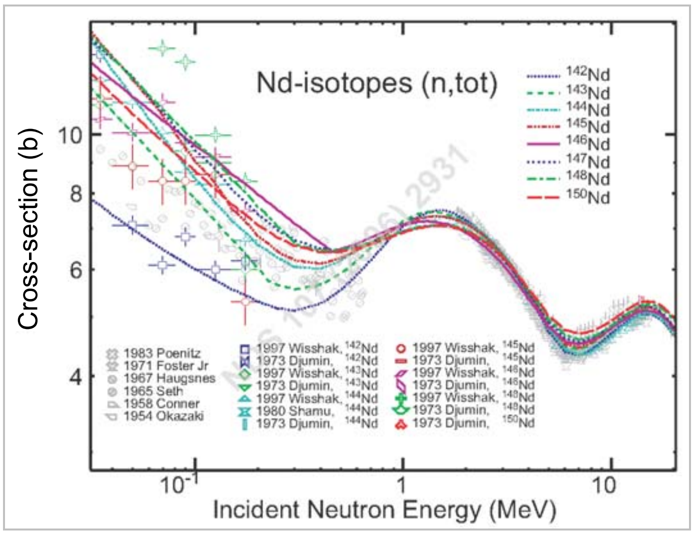


Figure 6: Evaluated capture cross-sections for eight isotopes of Nd compared with data

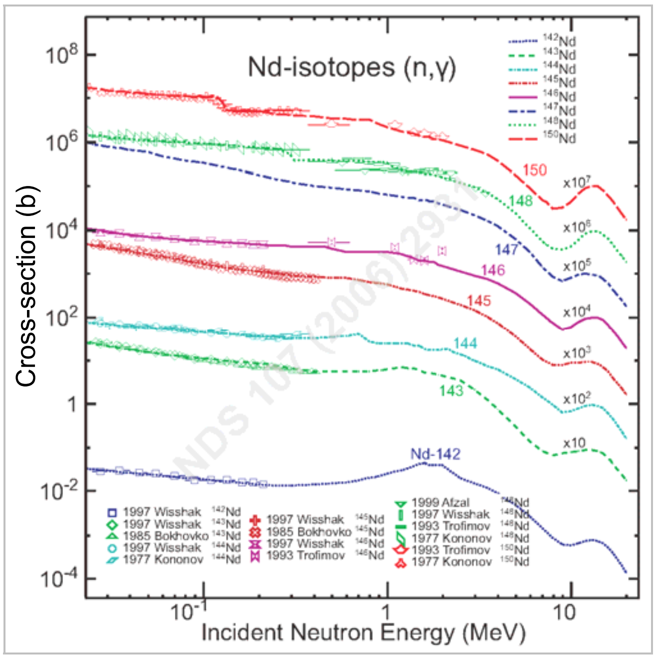


Figure 7: Evaluated (n,2n) cross-sections for nine isotopes of Sm compared with data

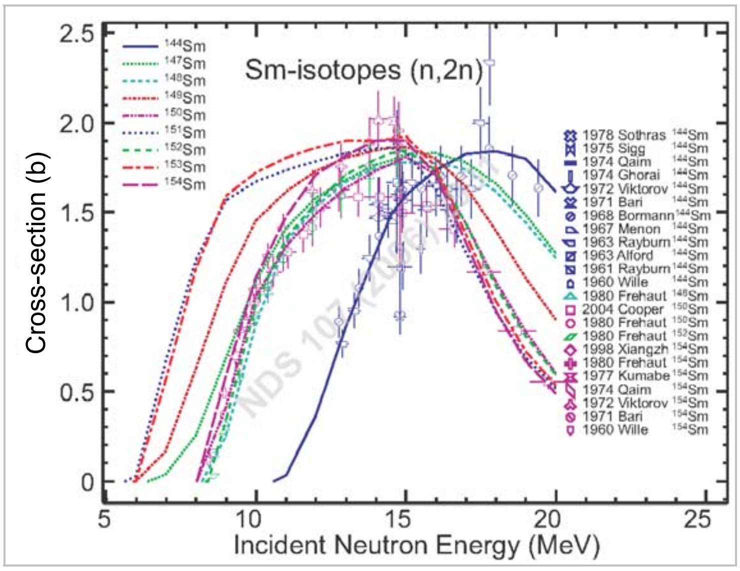
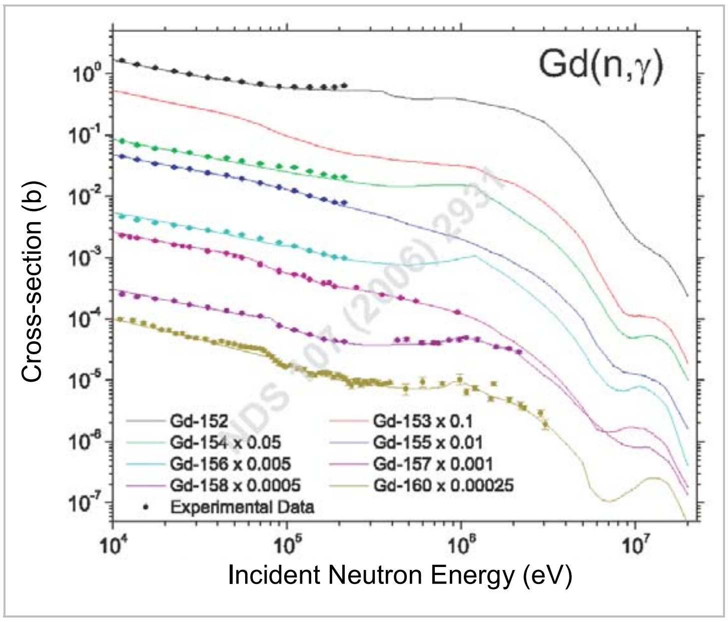


Figure 8: Evaluated capture cross-sections for eight isotopes of Gd compared with data



Creation of SG23 library

Assembly of the fission product library was the core of SG23 activity. The first step was the assembly of individual files. This was a complex task, as many files had to be compiled from different sources. Each file was subject to basic checking, including careful inspection of cross-section plots. Of particular concern was the smooth transition between the MF2 resonance region followed by the unresolved resonance region and MF3 cross-sections in the fast neutron region. This led to numerous adjustments that were applied mostly to materials obtained by merging two different evaluations.

The library was created in two steps. An initial version was put together in 2004-2005 and made available for review and comments. Feedback was collected during 2006 and numerous fixes were applied. The final version was assembled in the fall of 2006, adopted in full by ENDF/B-VII.0 and followed by official release in December 2006.

Initial version of the library

In 2004-2005, the initial version of the library was assembled. In order to convey a notion of the considerable amount of work involved, several key steps of the process are summarised here. These steps are also documented on the SG23 web page, see *www.nndc.bnl.gov/sg23*.

- Cleaning of files, consisting of format corrections and unification, was done by C. Dunford (BNL) for all files recommended by SG21. This work was followed by merging of files from different libraries as necessary. In this way the initial SG23 library with 164 files was created.
- V.G. Pronyaev (IPPE Obninsk) reviewed and adjusted many of these 164 files. His work was complemented by that of T. Nakagawa (JAEA Tokai-mura) who reviewed and adjusted JENDL-adopted files to match the latest JENDL-3.3 release. For a full account of this process see Pronyaev (2005).

The review process was organised in the following way (Pronyaev, 2005). For each file, PSYCHE-7.01 was run. Total, elastic and capture cross-sections at a thermal energy of 0.0253 eV and capture resonance integral (RI) were compared with the experimental data available in EXFOR and with the Mughabghab evaluation (2003) [tentative, later replaced by (Mughabghab, 2005)]. Cross-section plots, available on the SG23 website, were also inspected. Differences outside the uncertainties assigned in Mughabghab (2003) were identified as shortages of the file. Each file was processed through LINEAR, RECENT and GROUPIE modules of the processing code NJOY-99. Averaged cross-sections obtained with GROUPIE were compared with the results of poor resolution experiments taken from EXFOR. Attention was paid to possible jumps in the averaged cross-sections at the boundary between RRR and URR and between URR and fast neutron energy (FAST) regions. Such jumps indicate the possible inconsistency of the cross-sections between different regions. Attention was also paid to the position of the last resonance for each partial wave in the RRR. If the last resonance was much below the upper boundary of the RRR, it was considered to be a possible indication of missed resonances.

Statistical analysis of the resonances in the RRR was done with the REBUS code (Sinitsa, 2001). In the analysis of the parameters, performed independently for each partial wave, the fits of the distributions, based on experimental data, were done with known model distributions (staircase plot for number of resonances, Porter-Thomas distribution for average neutron widths and Wigner distribution for the average distance between the resonances). This also allowed making conclusions about the number, widths and energy ranges of missed resonances.

The INTER code was used to independently calculate RI and Maxwellian spectrum averaged capture cross-sections at different temperatures. A number of experimental data exists on astrophysical cross-sections at neutron energies corresponding to temperatures kT between 10 keV and 150 keV, mostly at 25 keV. This allows verifying if there is a loss of capture area in the RRR or inconsistency with cross-sections evaluated for URR. Because INTER runs after pre-processing it generally produces different results from those obtained with the PSYCHE code, which is uses the original file for calculations of contributions to the RI from the RRR, URR and FAST regions. To make RI more comparable, the SIGMA1 code was not used in the pre-processing of the data for INTER and all RI results are given at 0 K temperature. Even in this case the RI calculated with PSYCHE and INTER may differ, because PSYCHE interpolates cross-sections in the URR when calculating RI, even though in general the contribution of the URR to the resonance integral is quite small when compared to the RRR. On the other hand, INTER interpolates parameters and adds additional energy points reconstructing cross-sections in the URR with the required accuracy. Because the shape of the capture cross-section in the URR is usually such that the second derivative is positive, the contribution to RI from URR parameters calculated with INTER is less or equal to that obtained with PSYCHE. The results also differ when only the RRR region contributes to RI.

In some cases, due to the absence of actual RI measurements, the evaluation of capture RI was only based on the evaluated resonance parameters and this should be taken into account.

Only levels with assigned l, and J^{π} as evaluated by Mughabghab (2006) in the RRR were introduced by us into the ENDF-6 formatted file in the phase of merging. In some cases this may lead to underestimation of capture area in the RRR. We note though that Mughabghab (2006) assigns l values for resonances with unknown l on the basis of the Bayesian method, and assigns J values randomly on the basis of a $(2J + 1)$ law thus mitigating this problem.

In a few cases the EVPAR code (n.d.) was employed to produce a set of evaluated URR parameters. The code uses a least square procedure to adjust the URR parameters using prior and experimental direct and derived values for the average distance between resonances, neutron and gamma strength functions, scattering radius, total and capture cross-sections. The code also allows the evaluation of the contribution of d-wave and f-wave resonances in cases when these contributions are important. In cases when the URR region extends to a few hundred keV, the contribution of the f-wave to capture cannot be neglected.

Once the core of the library was assembled and individual files were reviewed and adjusted, the work focused on completion of new evaluations.

- In close collaboration with BNL, H-I. Kim (KAERI) completely re-evaluated the fast region for 15 priority materials, and also the chain of Nd and Sm. BNL re-evaluated the remaining priority materials including a complete set of eight isotopes of Gd, as well as ^{99}Tc and ^{153}Eu. Also in collaboration with BNL, O. Iwamoto (JAEA Tokai-mura) evaluated a complete set of five Ge isotopes.

- In addition, BNL supplied evaluations for 25 fairly low priority materials. It should be noted that some of these low priority materials, for which no resonance data were available, contain simple MF2 estimates generated by Mughabghab. These estimates were done for ^{85}Kr, ^{86}Rb, ^{90}Y, ^{111}Ag, ^{115m}Cd, ^{125,126}Sn, ^{132}Te, ^{130}I, ^{140}La, ^{138,139,143}Ce, ^{142}Pr, ^{151}Pm and ^{157}Eu.

As the next step, the NNDC assembled the complete library, with a tendency to give preference to new evaluations as they become available. Consequently, in this process some original SG21 recommendations were overruled.

- NNDC assembled the initial complete version of the SG23 library for a full set of 218 materials covered by SG21 plus ^{74}As, that making a total of 219 materials.

- Phase1 testing of the SG23 library was performed as follows. First, data verification was undertaken by looking into each file with three CSEWG standard checking codes (CHECKR, FIZCON and PSYCHE). Then, the Los Alamos processing code NJOY-99.90 was used to process the whole library. Finally, simple neutronics runs with the Los Alamos Monte Carlo code MCNP5 were successfully performed. The goal was to ensure that the library can be used in neutronics calculations.

- Afterwards, the initial version of the SG23 library was made available for review and comments to a broader community *via* the SG23 web page.

Final version of the library

The library was finalised in 2006. Feedback from the SG23 team and also from other data developers and data users was collected and numerous fixes were implemented. Often these were minor format error fixes, not noted during the basic NJOY-99 runs.

Once these fixes were made, the final version of the library was assembled and made subject of another round of Phase 1 testing as described above. The full list of 219 nuclides and the final selection of evaluations included in the SG23 library can be found in the Appendix.

In view of the culmination of work on release of the new US evaluated data library ENDF/B-VII.0, the final version of the SG23 library was reviewed by CSEWG and the decision was made to take it over in a complete form. Thus, all 219 files produced by SG23 were adopted by the ENDF/B-VII.0 library that was officially released in December 2006. As a consequence the new US evaluated library ENDF/B-VII.0 is a reliable and easily accessible source of the SG23 library.

Validation

Validation was performed on a partial basis. It should be understood that the SG23 library contains 219 materials, the vast majority for which no suitable benchmark experiments are available. This makes it virtually impossible to undertake detailed benchmarking.

Validation was made up of three components. First, basic testing was done by CSEWG in the United States as a part of the ENDF/B-VII.0 release along with some more specific validation performed in 2006 (Chadwick, 2006; Marck, 2006). This process continued during 2007-2008, with findings such as those described in (Mosteller, 2007, 2008); see also "Deficiencies and Benchmarking" under the ENDF/B-VII.0 web page. Second, ORNL undertook benchmarking and assessment of fission product cross-sections for burn-up credit calculations (Leal, 2007). Third, validation was conducted in Europe with a focus on a dozen of the most important fission products as reported by Dean, *et al.* (2008) at the International Conference on Nuclear Data for Science and Technology.

CSEWG testing

Basic validation of the ENDF/B-VII.0 library, including the full set of fission product materials, was done by the CSEWG Validation Committee as detailed by Chadwick (2006). This was complemented by extensive benchmark calculations by Marck (2006), who focused on k_{eff} benchmarks for more than 700 assemblies. This set included a relatively small fraction (about 40 assemblies) in which elements are present, either with more than 1 wt.% or with more than 1e-4 atoms/barn-cm:

Ga: pmf01, pmf02, pmf05, pmf06, pmf08, pmf12, pmf13, pmm01
Zr: lct09, lct16, lct60, ict03, hci05, hcm03, pmf05, kritz, mmf11, u3ct01
Nb: lct60, imf07, hcm03
Mo: ict03, hmt16, hst42, hci05, hcm03, hmf05
Cd: lct09, lct16, ict02, hst38, hmt06, hmm05, pst08, pmm01
Sn: lct09, kritz, u3ct01
Gd: ict02, hmt10, hmt16

Here, for each of the three components of the ICSBEP name we use the first characters as follows: LEU → l, COMP → c, THERM → t, which gives "lct01" for LEU-COMP-THERM-001. Similarly, PU-MET-FAST-001 is abbreviated as "pmf01".

The calculations have been performed and summary results are available in both graphical and numerical form (Marck, 2006). An overall conclusion was that the performance of the library is in general very good. Sensitivities to fission products, however, were often fairly small and therefore no detailed conclusions on fission product performance could be drawn.

On the other hand, the results for the fusion shielding benchmarks have changed quite a bit as compared to ENDF/B-VI.8. Especially noticeable is that considerable improvement of the results for Mo and Zr.

In three separate instances the CSEWG Validation Committee made more specific observations on performance.

^{90}Zr

This material is part of SG23, even though zirconium is viewed more as a structural material rather than a typical fission product. Zirconium is important because of its corrosion resistance and low absorption cross-sections for thermal neutrons and it is used in fuel rod cladding. The initial version of the SG23 library contained a full set of Zr isotopes. Benchmark testing performed at Bettis and KAPL (Lubitz, 2006) showed an undesirable drop in the reactivity. Sensitivity studies indicated that this shortage could be counteracted by the increase of the elastic cross-section in ^{90}Zr. These corrections were performed by BNL and included in the final version of the library.

^{113}Cd

Calculations with both the ENDF/B-VI.8 and ENDF/B-VII.0 libraries have demonstrated poor agreement with benchmark values for k_{eff} for several benchmarks with HEU nitrate solutions containing natural cadmium with several concentrations. This discrepancy was attributed to the high thermal capture cross-section of ^{113}Cd (Mosteller, 2007, 2008). On this basis, a new evaluation of the first resonance of this isotope resulted in a reduction of its scattering width from 0.6533 to 0.6220 meV. This revision would then generate a 2 200 m/sec capture cross-section of 19 800 b and a capture resonance integral of 376.6 b. Previously accepted values are 20 615±400 b and 390 b (computed), respectively (Mughabghab, 2006). These changes substantially improved the agreement with benchmark values for k_{eff}. It is anticipated that this revised evaluation will be included into the next release of the ENDF/B-VII library.

^{157}Gd

There are continuous indications that gadolinium is not performing well in reactor applications, though there is little evidence as to what might be causing the problem. It should be noted that the recent Leinweber (2006) measurement indicates that the thermal capture cross-section is 11% lower than the currently employed value. This important new result will require careful analysis and independent confirmation. Indeed, two measurements are currently under way to investigate this issue, at Geel in Belgium and at RPI Troy in the United States.

ORNL benchmarking

ORNL made an assessment of fission product cross-sections for burn-up credit calculations and published a detailed report in December 2007 (Leal). This work was driven by the objective to meet the needs of regulators.

Past efforts by the Department of Energy, the Electric Power Research Institute (EPRI), the Nuclear Regulatory Commission (NRC) and others have provided sufficient technical information to enable the NRC to issue regulatory guidance for implementation of pressurised water reactor (PWR) burn-up credit; however, consideration of only the reactivity change due to the major actinides is recommended in the guidance. Moreover, DOE, NRC and EPRI have noted the need for additional scientific and technical data to justify expanding PWR burn-up credit to include fission product (FP) nuclides and enable burn-up credit implementation for boiling water reactor (BWR) spent nuclear fuel (SNF).

The criticality safety assessment needed for burn-up credit applications will utilise computational analyses of packages containing SNF with FP nuclides. Over the years, significant efforts have been devoted to the nuclear data evaluation of major isotopes pertinent to reactor applications (*i.e.* uranium, plutonium, etc.); efforts to evaluate FP cross-section data in the resonance region, however, have been less thorough relative to actinide data. In particular, resonance region cross-section measurements with corresponding R-matrix resonance analyses have not been performed for FP nuclides. Therefore, the objective of the ORNL work was to assess the status and performance of existing FP cross-section and cross-section uncertainty data in the resonance region for use in burn-up credit analyses. Recommendations for new cross-section measurements and/or evaluations were made based on the data assessment.

The ORNL benchmarking and assessment focused on seven primary FP isotopes that impact reactivity analyses of transportation packages, and two FP isotopes that impact prediction of ^{155}Gd concentrations:

- ^{103}Rh, ^{133}Cs, ^{143}Nd, ^{149,151,152}Sm and ^{155}Gd;
- ^{153,155}Eu.

Much of the ORNL assessment work was completed in 2005, and the assessment focused on the latest FP cross-section evaluations available in the international nuclear data community as of March 2005. The accuracy of the cross-section data was investigated by comparing existing cross-section evaluations against available measured cross-section data. When possible, benchmark calculations were also used to assess the performance of the latest FP cross-section data.

Since March 2005, the US and European data projects have released newer versions of their respective data files. Although there have been updates to the international data files and to some degree FP data, many of the updates have included nuclear cross-section modelling improvements at energies above the resonance region. The one exception is improved ENDF/B-VII cross-section uncertainty data or covariance data for gadolinium isotopes. In particular, ENDF/B-VII includes improved ^{155}Gd resonance parameter covariance data, but they are based on previously measured resonance data. Although the new covariance data are available for ^{155}Gd, the conclusions of the FP cross-section data assessment of this report still hold in lieu of the newer international cross-section data files.

In reference to the ENDF/B-VII.0 library it should be pointed out eight out of nine evaluations (all but ^{155}Eu) addressed by ORNL had already been updated for the ENDF/B-VI.8 library released in October 2001. These updates were based on the work of Oh, Chang and Mughabghab (2000) and covered both the resolved resonance and unresolved resonance regions, with the URR extended to the first excited state of the target nuclei. As a consequence the relevant differences between the ENDF/B-VII.0 and ENDF/B-VI.8 evaluations are minor. This means that the conclusions and findings of the ORNL benchmarking study (Leal, 2007), with the exception of ^{155}Eu, are valid even though they used preliminary ENDF/B-VII data rather than those included in the final version of the ENDF/B-VII.0 library released in December 2006.

The benchmarking procedure adopted by ORNL includes the following major items:

- The accuracy of the data was investigated using differential and integral data. Measured differential data were retrieved from the EXFOR system and compared with continuous-energy cross-sections obtained from the evaluated nuclear data libraries processed with the NJOY and AMPX code systems.
- To verify the adequacy of the evaluated data in integral benchmark calculations, MCNP and SCALE were used to investigate the performance of the FP data in benchmark calculations:
  - The cross-sections for ^{103}Rh and ^{149}Sm were assessed using integral benchmark experiments. Reactivity worth measurements carried out at the French Atomic Energy Commission at Cadarache were used to assess the cross-sections for ^{103}Rh, ^{133}Cs, ^{153}Eu, ^{143}Nd and ^{149}Sm.
  - With regard to ^{155}Gd, critical benchmark experiments involving gadolinium are available in open literature; however, the available benchmarks do not exhibit strong sensitivity to ^{155}Gd. Benchmark experiments that are sensitive to ^{155}Gd are available in the CERES experimental programme involving UO_2 in the MINERVE and DIMPLE reactors; however, these data are not available in open literature. Based on the summary of C/E results, the ^{155}Gd cross-section data underpredict the experimental capture rate by 2-3%.
  - With regard to the remaining fission products, integral benchmark data sensitive to the ^{151}Sm, ^{152}Sm and ^{155}Eu cross-sections are not available. The resonance parameters for ^{151}Sm, ^{152}Sm, ^{155}Gd and ^{155}Eu in the existing cross-section libraries are basically the parameters listed in the Mughabghab compilation with minor modifications.

The resonance parameters listed in the Mughabghab compilation are a collection of evaluations used to investigate issues related to nuclear physics. Moreover, these parameters do not represent R-matrix analysis of all resonances that are measured throughout the resonance region. The Mughabghab parameters are typically used as a starting point for a resonance analysis of measured cross-section data. Therefore, the authors of the ORNL study recommend that measured cross-section data with a corresponding R-matrix analysis be used to improve evaluations that are based solely on the compilation of Mughabghab resonance parameters.

Based on the fission product data assessment, there is a need for new total and capture cross-section measurements and corresponding cross-section evaluations, in a prioritised manner, for the nine fission products to provide the improved information and technical rigour needed for criticality safety analyses.

The recommended fission product measurements are provided in Table 2 and a tabulated summary of assessment is shown in Table 3. The basis for the recommendations in these tables provides a quick-reference summary of the cross-section data assessment. For the fission products noted in Table 2, new cross-section measurements and corresponding cross-section evaluations would improve confidence in reactivity predictions in burn-up credit applications. Also given, for each fission product, is the priority identified according to the importance for burn-up credit.

Benchmarking in Europe

In order to assess the quality of important fission product files Dean, *et al.* studied the CERES benchmark and presented a paper at the ND2007 conference (2007). This work was motivated by the need for the optimisation of energy resources that suggests increased fuel residence in reactor cores and hence the need for improved fission product evaluations.

For thermal reactors the fission product cross-sections in the JEF-2.2 and JEFF-3.1 libraries plus new evaluations from SG23 were assessed through modelling the CERES experiment in the DIMPLE reactor. The analysis used the lattice code WIMS10. Cross-sections for 12 nuclides were assessed and the findings are summarised in Table 4.

Table 2: ORNL recommended fission product cross-section measurements

Priority for burn-up credit	FP	Applicable energy range for burn-up credit	Total cross-sections	Capture cross-sections
1	^{149}Sm	0.0253-1 eV	10^{-5} eV through RRR	10^{-5} eV through RRR
2	^{143}Nd	0.0253-600 eV	10 eV through RRR	10 eV through RRR
3	^{103}Rh	0.0253-3 eV	10^{-5} eV-1 eV	10^{-5} eV through RRR
4	^{151}Sm	0.0253-10 eV	4 eV through RRR	10^{-5} eV through RRR
5	^{133}Cs	0.0253-1 keV	10 eV through RRR	10^{-5} eV through RRR
6	^{155}Gd	0.0253-5 eV	10^{-5} eV through RRR	10^{-5} eV through RRR
7	^{152}Sm	0.0253-100 eV	10^{-5} eV through RRR	10^{-5} eV through RRR
8	^{153}Eu	0.0253-1 keV	10^{-5} eV through RRR	10^{-5} eV through RRR
9	^{155}Eu	0.0253-1 eV	10^{-5} eV through RRR	10^{-5} eV through RRR

Table 3: ORNL assessment summary for nine fission product evaluations

FP	Measured data available in EXFOR		Finding from benchmark criticality experiments	Finding from reactivity worth experiments	GBC-32 cask % Δk/k
	Total	Capture			
^{149}Sm	6.47×10^{-4} eV to 0.028 eV	N/A	Capture worth underestimated	Capture rate underestimated by 4.8%	0.023
^{143}Nd	10^{-2} to 10 eV 60 eV to 30 keV	10^{-2} to 10 eV	N/A	Capture rate underestimated by 0.7-8.5%	0.037
^{103}Rh	18 eV to 4.2 keV	100 eV to 20 MeV 0.39 to 34 keV	Not conclusive	Capture rate overestimated by 8-12.9%	0.022
^{151}Sm	10^{-5} to 4 eV	N/A	N/A	N/A	0.015
^{133}Cs	0.6 to 20 eV 0.016 to 4.4 eV 11 to 570 eV	N/A	N/A	Capture rate overestimated by 5.5%	0.015
^{155}Gd	0.0195 to 0.2793 eV	0.0253 eV	Not conclusive	Capture rate underestimated by 2-3%	0.003
^{152}Sm	N/A	N/A	N/A	Capture rate underestimated by ~8%	0.007
^{153}Eu	10^{-3} to 1 eV	10^{-2} to 1 eV 1 to 10 eV	N/A	Not conclusive	0.007
^{155}Eu	N/A	0.0253 eV	N/A	N/A	0.008

The thermal cross-section and low energy resonance data for ^{147,152}Sm and ^{155}Gd are accurate to within 4%. Similar data for ^{109}Ag, ^{143}Nd and ^{149}Sm are within 8% while ^{95}Mo, ^{99}Tc, ^{103}Rh, ^{133}Cs and ^{145}Nd are within three benchmark standard deviations at ~12%. The use of the 172-group structure is adequate for all nuclides considered except ^{153}Eu. These findings were supported by private confirmation from the CEA that they agree with the overall conclusions regarding the need for further improvement of the ^{95}Mo, ^{99}Tc, ^{103}Rh, ^{133}Cs and ^{145}Nd files.

Due to the fact that the ND2007 paper (Dean, 2007) validated an early version of the SG23 library rather than the latest version included in ENDF/B-VII.0, an additional effort was made to compare the evaluations used with those in ENDF/B-VII.0. This is summarised in Table 4 (Dean, 2008). Each CERES fission product is listed in Column 1. The recorded discrepancies between calculated and measured reactivity worth are then provided in Columns 2 and 3. The experiment in DIMPLE used two cores. The first simulated a uranium-fuelled PWR with a relatively hard spectrum. The second contained a large D_2O tank between the fuel and the irradiated samples. This leads to a soft spectrum emphasising the thermal cross-section rather than the first few resonances. Reported results for the hard spectrum are in Column 2 and those for the soft spectrum are in Column 3. Based on the analysis of the relevant differences between the files (*i.e.* early SG23 library and ENDF/B-VII.0) the last column describes the expected effect of the evaluation changes on the results.

Table 4: Summary of validation by Dean, *et al*. (2007, 2008)

The last column lists expected impact of differences between SG23 preliminary library and the final version adopted by ENDF/B-VII.0

Fission product	Difference in reactivity worth (C/E-1)%		Comments on impact due to differences between SG23 preliminary library and ENDF/B-VII.0
	Hard spectrum	Soft spectrum	
^{95}Mo	0	+9	No impact.
^{99}Tc	+10	+10	Expected to be insensitive to the unresolved range but increasing thermal capture cross-section would give worse agreement relative to measurement.
^{103}Rh	+8	+12	No impact.
^{109}Ag	+2	+5	No impact.
^{133}Cs	+10	+11	No impact.
^{143}Nd	-6	-2	No impact.
^{145}Nd	+11	+13	No impact.
^{147}Sm	0	+3	Relevant changes, which can only worsen comparison and bring the consistency outside of the standard deviation to the category “orange” (two sigma) instead of “green” (one sigma).
^{149}Sm	-6	0	ENDF/B-VII.0 is expected to give more discrepant results than those obtained with the preliminary file.
^{152}Sm	0	-1	Very good results, they should remain so with ENDF/B-VII.0.
^{153}Eu	-6	-11	No change expected, however the adopted WIMS 172-group structure does not represent resonances well and calculated results could not be guaranteed to be reliable.
^{155}Gd	+3	+4	No differences expected.

In the above process each fission product evaluation from the files benchmarked was compared with the equivalent file in ENDF/B-VII.0 using the UNIX “diff” command. This has shown many differences due to layout of comments and to high-energy cross-sections and emission data. It does allow one to confirm whether there are any changes to resonance parameter or background cross-sections in the resolved and unresolved resonance ranges. JANIS was then used to compare the capture cross-section in these files with those in its ENDF/B-VII.0 database. There are expected to be very small differences due to different parameters being used in the WINFRITH NJOY processing from those used for construction of the ENDF/B-VII.0 database. Also, the definition of “room temperature” may be trivially different. In summary, however, the impact should be fairly small and the findings of Dean (2007) are applicable to final SG23 evaluations as well.

Conclusions

Our major conclusion is that following its charge the WPEC Subgroup 23 created the Evaluated Data Library for the Bulk of Fission Products, internationally identified as NLIB=21.

Subgroup 23 performed a considerable amount of work. Over a period of three years (2004-2006) it assembled files for 219 fission product materials from a variety of sources. These files were inspected, checked and adjustments were made as necessary. Then, the full library was assembled and subjected to a data verification process and testing. The final version of the library was then released in December 2006.

This official release was followed by a more focused, though still limited, effort on detailed benchmarking that continued through the years 2007-2008. The validation done by CSEWG concluded that ^{113}Cd and ^{157}Gd evaluations should be improved; validation in Europe revealed the need for further study of ^{95}Mo, ^{99}Tc, ^{103}Rh, ^{133}Cs and ^{145}Nd; independent assessment by ORNL concluded that in addition to ^{103}Rh and ^{133}Cs improvements are needed for ^{143}Nd, ^{149,151,152}Sm, ^{155}Gd and ^{153,155}Eu.

Overall, the SG23 library performs fairly well and it has been adopted in full by the new United States library ENDF/B-VII.0 released in December 2006. Thus, this latter library represents a reliable and easily accessible source of a complete set of evaluations for 219 fission product materials produced by the WPEC SG23 effort.

The most recent extensive review of evaluated data libraries was performed at IPPE Obninsk in Russia. Reactor physicists and nuclear data evaluators participated in a common effort to select the best evaluations for the RUSFOND library; at the conclusion of their work, they had adopted SG23 evaluations for 152 materials.

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Appendix: List of SG23 nuclides and evaluations

Table A1. List of 219 nuclides in the fission product range (Z = 31-68) included in the SG23 library

31-Ga-	69, 71
32-Ge-	70, 72, 73, 74, 76
33-As-	74, 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

Table A2. List of 219 evaluations included in the SG23 library

Sequence number, material (nuclide), laboratory of origin, date of evaluation, short list of evaluators and MAT number are provided

#	Material	Laboratory	Date	Evaluators	MAT
1.	31-Ga- 69	KHI, BNL	Jan05	T. Watanabe, Mughabghab	3125
2.	31-Ga- 71	CNDC	Oct98	Song-Bai Zhang, B.S. Yu ,Z.J. Zhang	3131
3.	32-Ge- 70	BNL, JAERI	Aug04	Iwamoto, Herman, Mughabghab+	3225
4.	32-Ge- 72	BNL, JAERI	Aug04	Iwamoto, Herman, Mughabghab+	3231
5.	32-Ge- 73	BNL, JAERI	Aug04	Iwamoto, Herman, Mughabghab+	3234
6.	32-Ge- 74	BNL, JAERI	Aug04	Iwamoto, Herman, Mughabghab+	3237
7.	32-Ge- 76	BNL, JAERI	Aug04	Iwamoto, Herman, Mughabghab+	3243
8.	33-As- 74	LANL	Feb06	D.A. Brown, H.I. Kim, Mughabghab	3322
9.	33-As- 75	LLNL	Feb06	D.A. Brown, Pruet, H.I. Kim	3325
10.	34-Se- 74	JNDC	Mar90	JNDC FP Nuclear Data W.G.	3425
11.	34-Se- 76	JNDC	Mar90	JNDC FP Nuclear Data W.G.	3431
12.	34-Se- 77	JNDC	Mar90	JNDC FP Nuclear Data W.G.	3434
13.	34-Se- 78	JNDC	Mar90	JNDC FP Nuclear Data W.G.	3437
14.	34-Se- 79	JNDC	Mar90	JNDC FP Nuclear Data W.G.	3440
15.	34-Se- 80	JNDC	Mar90	JNDC FP Nuclear Data W.G.	3443
16.	34-Se- 82	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	3449
17.	35-Br- 79	JNDC	Mar90	JNDC FP Nuclear Data W.G.	3525
18.	35-Br- 81	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	3531
19.	36-Kr- 78	JNDC, BNL	Feb05	JNDC FPND W.G., Mughabghab	3625
20.	36-Kr- 80	JNDC	Mar90	JNDC FP Nuclear Data W.G.	3631
21.	36-Kr- 82	JNDC, BNL	Feb05	JNDC FPND W.G., Mughabghab	3637
22.	36-Kr- 83	CNDC	Jun99	You-Xiang Zhuang, Chong-Hai Cai	3640
23.	36-Kr- 84	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	3643
24.	36-Kr- 85	BNL	Mar06	Herman, Oblozinsky, Mughabghab	3646
25.	36-Kr- 86	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	3649
26.	37-Rb- 85	JNDC	Mar90	JNDC FPND WG + Mughabghab	3725
27.	37-Rb- 86	BNL	Mar06	Herman, Oblozinsky, Mughabghab	3728
28.	37-Rb- 87	JNDC	Mar90	JNDC FP Nuclear Data W.G.	3731
29.	38-Sr- 84	BNL	Mar06	Herman, Oblozinsky, Mughabghab	3825
30.	38-Sr- 86	JNDC, BNL	Feb05	JNDC FPND W.G., Mughabghab	3831
31.	38-Sr- 87	JNDC	Mar90	JNDC FP Nuclear Data W.G.	3834
32.	38-Sr- 88	CNDC, BNL	Feb05	Zhuang, Cai, Mughabghab	3837
33.	38-Sr- 89	CNDC	Sep01	Yin-Lu Han, C.H. Cai, Y.X. Zhuang	3840
34.	38-Sr- 90	JNDC	Mar90	JNDC FP Nuclear Data W.G.	3843
35.	39-Y - 89	BNL-LANL	Aug06	Rochman, Chadwick, Herman, Kawano+	3925
36.	39-Y - 90	BNL	Mar06	Herman, Oblozinsky, Mughabghab	3928
37.	39-Y - 91	JNDC	Mar90	JNDC FP Nuclear Data W.G.	3931
38.	40-Zr- 90	BNL	Sep06	Herman, Rochman, Oblozinsky	4025
39.	40-Zr- 91	JNDC, BNL	Feb05	JNDC FPND W.G., Mughabghab	4028
40.	40-Zr- 92	JNDC	Aug89	JNDC FP Nuclear Data W.G.	4031
41.	40-Zr- 93	JNDC, BNL	Mar05	JNDC FPND W.G., Mughabghab	4034
42.	40-Zr- 94	JNDC, BNL	Mar05	JNDC FPND W.G., Mughabghab	4037
43.	40-Zr- 95	JNDC	Mar90	JNDC FP Nuclear Data W.G.	4040

#	Material	Laboratory	Date	Evaluators	MAT
44.	40-Zr- 96	JNDC, BNL	Feb05	JNDC FPND W.G., Mughabghab	4043
45.	41-Nb- 93	LANL, ANL	Dec97	M. Chadwick, P. Young, D.L. Smith	4125
46.	41-Nb- 94	JNDC	Mar90	JNDC FP Nuclear Data W.G.	4128
47.	41-Nb- 95	NDC	Mar90	JNDC FP Nuclear Data W.G.	4131
48.	42-Mo- 92	JNDC	Aug89	JNDC FP Nuclear Data W.G.	4225
49.	42-Mo- 94	JNDC, BNL	Feb05	JNDC FPND W.G., Mughabghab	4231
50.	42-Mo- 95	BNL, KAERI	Feb06	Kim, Herman, Oh, Mughabghab+	4234
51.	42-Mo- 96	JNDC	Aug89	JNDC FP Nuclear Data W.G.	4237
52.	42-Mo- 97	JNDC, BNL	Feb05	JNDC FPND W.G., Mughabghab	4240
53.	42-Mo- 98	JNDC	Aug89	JNDC FP Nuclear Data W.G.	4243
54.	42-Mo- 99	JNDC	Mar90	JNDC FP Nuclear Data W.G.	4246
55.	42-Mo-100	CNDC	Aug00	Chong-Hai Cai and Qi-Chang Liang	4249
56.	43-Tc- 99	BNL-LANL	May06	Oblozinsky, Rochman, Herman, Mughab	4325
57.	44-Ru- 96	JNDC	Mar90	JNDC FP Nuclear Data W.G.	4425
58.	44-Ru- 98	JNDC	Mar90	JNDC FP Nuclear Data W.G.	4431
59.	44-Ru- 99	JNDC	Mar90	JNDC FP Nuclear Data W.G.	4434
60.	44-Ru-100	JNDC, BNL	Mar05	JNDC FPND W.G., Mughabghab	4437
61.	44-Ru-101	BNL, KAERI	Feb06	Kim, Herman, Oh ,Mughabghab+	4440
62.	44-Ru-102	NDC, BNL	Feb05	Qi-Chang Liang+, Mughabghab	4443
63.	44-Ru-103	CNDC, BNL	Feb05	Z.G. Ge+, Mughabghab	4446
64.	44-Ru-104	CNDC	Jun99	Zhang, Liang, Shen, Sun	4449
65.	44-Ru-105	CNDC	Jun00	Qi-Chang Liang,Z.J. Zhang,X.Q. Sun	4452
66.	44-Ru-106	JNDC	Mar90	JNDC FP Nuclear Data W.G.	4455
67.	45-Rh-103	NL, KAERI	Feb06	Kim, Herman, Chang, Mughabghab+	4525
68.	45-Rh-105	CNDC	Dec99	Sun, Zhang, Shen, Zhao, Su	4531
69.	46-Pd-102	LANL, BNL	Mar05	P.G. Young, Mughabghab	4625
70.	46-Pd-104	LANL, BNL	Mar05	P.G. Young, Mughabghab	4631
71.	46-Pd-105	BNL, KAERI	Feb06	Kim, Herman, Oh, Mughabghab+	4634
72.	46-Pd-106	LANL, BNL	Mar05	P.G. Young, Mughabghab	4637
73.	46-Pd-107	JNDC	Mar90	JNDC FP Nuclear Data W.G.	4640
74.	46-Pd-108	LANL, BNL	Mar05	P.G. Young, Mughabghab	4643
75.	46-Pd-110	LANL, BNL	Mar05	P.G. Young, Mughabghab	4649
76.	47-Ag-107	JAERI, BNL	Mar05	Liu+, Mughabghab	4725
77.	47-Ag-109	BNL, KAERI	Feb06	Kim, Herman, Oh, Mughabghab+	4731
78.	47-Ag-110M	JNDC, BNL	Mar05	JNDC FPND W.G., Mughabghab	4735
79.	47-Ag-111	BNL	Mar06	Herman, Oblozinsky, Mughabghab	4737
80.	48-Cd-106	JNDC, BNL	Mar05	JNDC FPND W.G., Mughabghab	4825
81.	48-Cd-108	UA, ANL, BNL	Mar05	J. McCabe, A.B. Smith, Mughabghab	4831
82.	48-Cd-110	UA, ANL, BNL	Mar05	J. McCabe, A.B. Smith, Mughabghab	4837
83.	48-Cd-111	JNDC, BNL	Mar05	JNDC FPND W.G., Mughabghab	4840
84.	48-Cd-112	UA, ANL, BNL	Mar05	J. McCabe, A.B. Smith, Mughabghab	4843
85.	48-Cd-113	CNDC, BNL	Mar05	J.W. Zhao+, Mughabghab	4846
86.	48-Cd-114	UA, ANL, +	Aug94	J. McCabe, A.B. Smith, +	4849
87.	48-Cd-115M	BNL	Mar06	Herman, Oblozinsky, Mughabghab	4853
88.	48-Cd-116	UA, ANL, BNL	Mar05	J. McCabe, A.B. Smith, Mughabghab	4855
89.	49-In-113	JNDC, BNL	Mar05	JNDC FPND W.G., Mughabghab	4925
90.	49-In-115	JNDC, BNL	Mar05	JNDC FPND W.G., Mughabghab	4931

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91.	50-Sn-112	JNDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5025
92.	50-Sn-113	BNL	Mar06	Herman, Oblozinsky, Mughabghab	5028
93.	50-Sn-114	NDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5031
94.	50-Sn-115	JNDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5034
95.	50-Sn-116	JNDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5037
96.	50-Sn-117	JNDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5040
97.	50-Sn-118	JNDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5043
98.	50-Sn-119	JNDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5046
99.	50-Sn-120	JNDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5049
100.	50-Sn-122	JNDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5055
101.	50-Sn-123	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5058
102.	50-Sn-124	JNDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5061
103.	50-Sn-125	BNL	Mar06	Herman, Oblozinsky, Mughabghab	5064
104.	50-Sn-126	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5067
105.	51-Sb-121	CNDC, BNL	Dec04	Zhao+, Mughabghab	5125
106.	51-Sb-123	CNDC, BNL	Dec04	Zhang+, Mughabghab	5131
107.	51-Sb-124	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5134
108.	51-Sb-125	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5137
109.	51-Sb-126	BNL	Mar06	Herman, Oblozinsky, Mughabghab	5140
110.	52-Te-120	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5225
111.	52-Te-122	JNDC, BNL	Mar90	JNDC FPND W.G., Mughabghab	5231
112.	52-Te-123	JNDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5234
113.	52-Te-124	JNDC, BNL	Dec04	JNFP W.G., Mughabghab	5237
114.	52-Te-125	JNDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5240
115.	52-Te-126	JNDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5243
116.	52-Te-127M	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5247
117.	52-Te-128	JNDC, BNL	Dec04	JNDC FPND W.G., Mughabghab	5249
118.	52-Te-129M	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5253
119.	52-Te-130	CNDC	Dec04	W.N.Su+, Mughabghab	5255
120.	52-Te-132	BNL	Mar06	Herman, Oblozinsky, Mughabghab	5261
121.	53-I -127	LANL, BNL	Jan05	Young, MacFarlane, Mughabghab	5325
122.	53-I -129	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5331
123.	53-I -130	BNL	Mar06	Herman, Oblozinsky, Mughabghab	5334
124.	53-I -131	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5337
125.	53-I -135	CNDC, BNL	Jan05	Shen, Sun, Zhang, Su, Zhao	5349
126.	54-Xe-123	CNDC	Oct00	Qing-Biao Shen	5422
127.	54-Xe-124	CNDC, BNL	Jan05	Yu, Shen, Mughabghab	5425
128.	54-Xe-126	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5431
129.	54-Xe-128	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5437
130.	54-Xe-129	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5440
131.	54-Xe-130	BNL	Jan05	M.R. Bhat+, Mughabghab	5443
132.	54-Xe-131	BNL, KAERI	Feb06	Kim, Herman, Oh, Mughabghab+	5446
133.	54-Xe-132	CNDC, BNL	Jan05	B.S. Yu+, Mughabghab	5449
134.	54-Xe-133	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5452
135.	54-Xe-134	CNDC, BNL	Jan05	B.S. Yu+, Mughabghab	5455
136.	54-Xe-135	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5458
137.	54-Xe-136	CNDC, BNL	Jan05	Q.B. Shen+, Mughabghab	5461

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138.	55-Cs-133	BNL, KAERI	Feb06	Kim, Herman, Oh, Mughabghab+	5525
139.	55-Cs-134	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5528
140.	55-Cs-135	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5531
141.	55-Cs-136	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5534
142.	55-Cs-137	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5537
143.	56-Ba-130	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5625
144.	56-Ba-132	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5631
145.	56-Ba-133	BNL	Mar06	Herman, Oblozinsky, Mughabghab	5634
146.	56-Ba-134	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5637
147.	56-Ba-135	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5640
148.	56-Ba-136	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5643
149.	56-Ba-137	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5646
150.	56-Ba-138	CNDC, BNL	Jan05	W.N. Su+, Mughabghab	5649
151.	56-Ba-140	NEA	Jul82	H. Gruppelaar, E. Menapace	5655
152.	57-La-138	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5725
153.	57-La-139	CNDC, BNL	Jan05	J.W. Zhao+, Mughabghab	5728
154.	57-La-140	BNL	Mar06	Herman, Oblozinsky, Mughabghab	5731
155.	58-Ce-136	BNL	Mar06	Herman, Oblozinsky, Mughabghab	5825
156.	58-Ce-138	BNL	Mar06	Herman, Oblozinsky, Mughabghab	5831
157.	58-Ce-139	BNL	Mar06	Herman, Oblozinsky, Mughabghab	5834
158.	58-Ce-140	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5837
159.	58-Ce-141	CNDC, BNL	Jan05	Zhang+, Mughabghab	5840
160.	58-Ce-142	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5843
161.	58-Ce-143	BNL	Mar06	Herman, Oblozinsky, Mughabghab	5846
162.	58-Ce-144	JNDC	Mar90	JNDC FP Nuclear Data W.G.	5849
163.	59-Pr-141	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	5925
164.	59-Pr-142	BNL	Mar06	Herman, Oblozinsky, Mughabghab	5928
165.	59-Pr-143	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	5931
166.	60-Nd-142	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6025
167.	60-Nd-143	BNL, KAERI	Feb06	Kim, Herman, Chang, Mughabghab+	6028
168.	60-Nd-144	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6031
169.	60-Nd-145	BNL, KAERI	Feb06	Kim, Herman, Chang, Mughabghab+	6034
170.	60-Nd-146	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6037
171.	60-Nd-147	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6040
172.	60-Nd-148	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6043
173.	60-Nd-150	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6049
174.	61-Pm-147	JNDC	Mar90	JNDC FP Nuclear Data W.G.	6149
175.	61-Pm-148	JNDC	Mar90	JNDC FP Nuclear Data W.G.	6152
176.	61-Pm-148M	CNDC	Sep01	You-Xiang Zhuang, Qing-Biao Shen	6153
177.	61-Pm-149	JNDC	Mar90	JNDC FP Nuclear Data W.G.	6155
178.	61-Pm-151	BNL	Mar06	Herman, Oblozinsky, Mughabghab	6161
179.	62-Sm-144	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6225
180.	62-Sm-147	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6234
181.	62-Sm-148	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6237
182.	62-Sm-149	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6240
183.	62-Sm-150	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6243
184.	62-Sm-151	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6246

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185.	62-Sm-152	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6249
186.	62-Sm-153	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6252
187.	62-Sm-154	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6255
188.	63-Eu-151	CNDC, BNL	Jan05	Ge+, Mughabghab	6325
189.	63-Eu-152	JNDC, ORNL	Mar05	JNDC FPND W.G., R.Q. Wright	6328
190.	63-Eu-153	BNL, KAERI	Sep02	Oblozinsky, Herman, Rochman, Chang+	6331
191.	63-Eu-154	CNDC, BNL	Jan05	Ge+, Mughabghab	6334
192.	63-Eu-155	CNDC	Feb99	You-Xiang Zhuang, Zhi-Gang Ge	6337
193.	63-Eu-156	JNDC	Mar90	JNDC FP Nuclear Data W.G.	6340
194.	63-Eu-157	BNL	Mar06	Herman, Oblozinsky, Mughabghab	6343
195.	64-Gd-152	BNL, ORNL+	Apr06	Rochman, Mughabghab, Leal, Kawano+	6425
196.	64-Gd-153	BNL, ORNL+	Apr06	Rochman, Mughabghab, Leal, Kawano+	6428
197.	64-Gd-154	BNL, ORNL+	Apr06	Rochman, Mughabghab, Leal, Kawano+	6431
198.	64-Gd-155	BNL, ORNL+	Apr06	Rochman, Mughabghab, Leal, Kawano+	6434
199.	64-Gd-156	BNL, ORNL+	Apr06	Rochman, Mughabghab, Leal, Kawano+	6437
200.	64-Gd-157	BNL, ORNL+	Apr06	Rochman, Mughabghab, Leal, Kawano+	6440
201.	64-Gd-158	BNL, ORNL+	Apr06	Rochman, Mughabghab, Leal, Kawano+	6443
202.	64-Gd-160	BNL, ORNL+	Apr06	Rochman, Mughabghab, Leal, Kawano+	6449
203.	65-Tb-159	JNDC, BNL	Jan05	JNDC FPND W.G., Mughabghab	6525
204.	65-Tb-160	BNL	Mar06	Herman, Oblozinsky, Mughabghab	6528
205.	66-Dy-156	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6625
206.	66-Dy-158	BNL, KAERI	Feb06	Kim, Mughabghab, Herman, Oblozinsky	6631
207.	66-Dy-160	BNL, KAERI	Feb06	Kim, Herman, Oh, Oblozinsky	6637
208.	66-Dy-161	BNL, KAERI	Feb06	Kim, Herman, Oh, Oblozinsky	6640
209.	66-Dy-162	BNL, KAERI	Feb06	Kim, Herman, Oh, Oblozinsky	6643
210.	66-Dy-163	BNL, KAERI	Feb06	Kim, Herman, Oh, Oblozinsky	6646
211.	66-Dy-164	BNL, KAERI	Feb06	Kim, Herman, Oh, Oblozinsky	6649
212.	67-Ho-165	LANL, BNL	Jan05	P.G. Young+, Mughabghab	6725
213.	67-Ho-166M	BNL	Mar06	Herman, Oblozinsky, Mughabghab	6729
214.	68-Er-162	TIT	Sep00	A.K.M. Harun-Ar-Rashid+	6825
215.	68-Er-164	TIT	Sep00	A.K.M. Harun-Ar-Rashid+	6831
216.	68-Er-166	TIT, BNL	Jan05	Harun-Ar-Rashid+, Mughabghab	6837
217.	68-Er-167	TIT, BNL	Jan05	Harun-Ar-Rashid+, Mughabghab	6840
218.	68-Er-168	TIT, BNL	Jan05	Harun-Ar-Rashid+, Mughabghab	6843
219.	68-Er-170	TIT, BNL	Jan05	Harun-Ar-Rashid+, Mughabghab	6849

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