EXFOR-based simultaneous evaluation of neutron-induced uranium and plutonium fission cross sections for JENDL-5

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\textbf{ABSTRACT}

The neutron-induced fission cross sections were simultaneously evaluated for the JENDL-5 library for \(^{233,235}\text{U}\) and \(^{239,241}\text{Pu}\) from 10 keV to 200 MeV and for \(^{238}\text{U}\) and \(^{240}\text{Pu}\) from 100 keV to 200 MeV. Evaluation was performed by least-squares fitting of Schmidthroth’s roof function to the logarithms of the experimental cross sections and cross section ratios in the EXFOR library. A simultaneous evaluation code SOK was used with its extension to data in arbitrary unit. The outputs of the code were adopted as the evaluated cross sections without any further corrections. The newly obtained evaluated cross sections were compared with the evaluated cross sections in the JENDL-4.0 library and the IAEA Neutron Data Standards 2017. The evaluated cross sections were also validated against the californium-252 spontaneous fission neutron spectrum averaged cross sections, \(\Sigma\Sigma\) (coupled thermal/fast uranium and boron carbide spherical assembly) neutron spectrum averaged cross sections, and small-sized LANL fast system criticalities. The changes in the obtained evaluated cross sections from those in the JENDL-4.0 library are within 4\% \((^{235}\text{Pu})\), 3\% \((^{233}\text{U}, 240\text{Pu})\), or 2\% \((^{234}\text{U}, 239\text{Pu})\). The newly evaluated \(^{235}\text{U}\), \(^{238}\text{U}\) and \(^{239}\text{Pu}\) cross sections agree with the IAEA Neutron Data Standards 2017 within 2\% with some exceptions.

\section{1. Introduction}

Fission is a major reaction channel in the interaction of low-energy neutrons with various actinide nuclides. Nuclear reaction systems such as thermal and fast reactors undergo fission, and the fission cross sections must be accurately known to understand the behavior of the systems. Fission cross sections such as \(^{235,238}\text{U}\) (n,f) cross sections are also important due to their use as references (standards) \cite{1,2,3} for determination of neutron fluence. The combination of the Hauser-Feshbach formalism and Hill-Wheeler formula describes fission cross sections for fast neutrons fairly well, and it has been implemented in various nuclear reaction model codes \cite{4,5,6,7}. Prediction of fission cross sections by this approach is sensitive to choice of parameters such as barrier heights, which must be adjusted to reproduce the experimental fission cross sections \cite{4}. On the other hand, fission events are relatively easy to detect, and many experimental datasets are available in the EXFOR library \cite{8}. For production of a nuclear data library, therefore, it is adequate to evaluate fission cross sections by fitting to the experimental cross sections without modelling the physics, and to evaluate the cross sections of other channels by a reaction model code with fission parameters adjusted to reproduce the evaluated fission cross sections \cite{9}.

Experimental fission cross sections for fast neutrons are often determined with the aid of reference cross sections. The measured ratio of the fission cross section to the reference cross section is free from choice of the reference cross section, and the ratio has been routinely compiled in the EXFOR library without conversion to the absolute cross section. One can include the cross section ratio to evaluation after conversion to the absolute cross sections by using a state-of-the-art reference cross section. But a more sophisticated way is to treat absolute cross sections (e.g. \(^{239}\text{Pu}\) and \(^{235}\text{U}\) fission cross sections) and their ratio (e.g. \(^{239}\text{Pu} / ^{235}\text{U}\) fission cross section ratio) in an equivalent manner without converting one to the other. Sowerby et al. \cite{10,11} and Poenitz \cite{12} are known as pioneers in this approach, and the JENDL project also has adopted this technique since its early versions. In its first attempt for the JENDL-2 library, evaluation of the \(^{235,238}\text{U}\) and \(^{239,240,241}\text{Pu}\)(n,f) cross sections from 100 eV to 20 MeV was divided into three steps – (1) preliminary evaluation for \(^{235}\text{U}\), (2)
normalization and evaluation for other target nuclides by using the preliminary $^{235}$U evaluation result, and (3) reevaluation for $^{238}$U to meet the requirements from the second step – to maintain consistency between the cross sections of all nuclides [13,14]. This first attempt was altered in JENDL-3 evaluation by developing a new simultaneous evaluation procedure based on least-squares fitting of the logarithms of the cross sections and their ratios to a B-spline function [15–17]. This method was applied to evaluation of $^{233,235,238}$U, $^{239,240,241}$Pu(n,f) and $^{197}$Au, $^{238}$U(n,γ) cross sections from 50 keV to 20 MeV [18] for the JENDL-3 library [19], which cross sections were also subsequently adopted in the JENDL-3.2 library with modifications such as replacement of the $^{235}$U(n,f) cross section above 13 MeV [20].

For the JENDL-3.3 library [21], a new simultaneous evaluation code SOK (Simultaneous evaluation on KALMAN) was developed for reevaluation of the $^{233,235,238}$U and $^{239,240,241}$Pu fission cross sections [22,23]. The JENDL-3.3 cross sections were further updated with SOK, and the updated cross sections were adopted in JENDL Actinoid File 2008 (JENDL/AC-2008) [24] and JENDL-4.0 library [25]. Apart from the JENDL project, the SOK code also analyzed the experimental database prepared for the IAEA Coordinated Research Project (CRP) ‘International Evaluation of Neutron Cross-Section Standards,’ and the Project concluded that SOK and another least-squares analysis code GMA [26] give very similar results or distinctive differences that can be readily explained [1,2].

As the evaluated data libraries tend to include more covariance information, the Nuclear Reaction Data Centres (NRDC) start to pay more attention to compilation of experimental uncertainty and covariance information, and also have extended the EXFOR format by introducing correlation property flags and computer readable format for matrices [27–30]. Meanwhile, a number of new experimental datasets relevant to the simultaneous evaluation were obtained at the time-of-flight facilities such as CERN n_TOF and LANSCE. The data newly published by CERN n_TOF collaboration have been compiled in the EXFOR library under tight collaboration with OECD NEA Data Bank and IAEA Nuclear Data Section [31]. From the view of validation, there was a progress in compilation of benchmark field neutron spectra and cross sections measured in the benchmark fields for the IRDFF-II project [32].

Considering these movements, we decided to perform simultaneous evaluation of $^{233,235,238}$U and $^{239,240,241}$Pu fission cross sections again by construction of an experimental database dedicated to the new evaluation.

This article reports the procedures and results of the new simultaneous evaluation for the JENDL-5 library [33]. We will compare the newly evaluated cross sections with the evaluated cross sections in the JENDL-4.0 library and the IAEA Neutron Data Standards 2017, and also discuss validation of the newly evaluated cross sections against the californium-252 prompt fission neutron spectrum averaged cross sections, $\Sigma$Σ (coupled thermal/fast uranium and boron carbide spherical assembly) spectrum averaged cross sections, and the small-sized LANL fast system criticalities.

2. Cross sections in major general-purpose and standard libraries

The fission cross sections of the six target nuclides treated in the present work are also included in the latest versions of major national general-purpose libraries (e.g. BROND-3.1 [34], CENDL-3.2 [35], ENDF/B-VIII.0 [36], JEFF-3.3 [37] and JENDL-4.0). Table 1 summarizes the origins of the evaluated cross sections to the best of our knowledge based on the description in the ENDF files (MF1 MT451) and evaluation summary documents (e.g. Ref [38–40] for the CENDL-3.2 cross sections taken from CENDL-2). This table shows that the evaluations are usually based on experimental works (data) but sometimes also done by statistical model calculation, which is also a reasonable choice especially for the subthreshold fission regions of $^{238}$U and $^{240}$Pu (below ~1 MeV).

We also observe that these general purpose libraries often adopt the cross sections evaluated for the IAEA Neutron Data Standards (IAEA-2006 [1,2], IAEA-2017 [3]) or ENDF/B-VI Neutron Cross Section Standards [41]. The cross sections in these standard libraries are obtained by GMA and R-matrix analysis. Their evaluations include not only $^{235,238}$U and $^{240}$Pu fission cross sections but also other important standard reactions such as $^6$Li(n,t)$^4$He, $^{10}$B(n,α)$^7$Li and $^{197}$Au(n,γ)$^{198}$Au cross sections. The thermal neutron constants (cross sections and average total neutron multiplicities) of $^{233}$U, $^{235}$U, $^{239}$Pu and $^{241}$Pu as well as the spontaneous fission neutron multiplicity of $^{252}$Cf have been also evaluated from the very early stage of this IAEA activity [42–45], and they are included in the experimental database of the GMA analysis (GMA database) since some measured cross sections are normalized to those at the thermal energy. The n-p scattering is also evaluated separately, and the experimental data of other standard reactions are renormalized in terms of the newly evaluated n-p scattering before GMA and R-matrix fitting. Namely, the experimental cross sections included in the IAEA standard evaluations are ultimately normalized with the latest values of the most fundamental n-p scattering cross section. Our present evaluation also uses the fission cross sections measured relative to the $^6$Li(n,t)$^4$He and $^{10}$B(n,α)$^7$Li standard cross sections.
Table 1. Evaluation procedures of $^{233,235,238}$U and $^{239,240,241}$Pu fast neutron fission cross sections in recent general purpose libraries.

| Target   | CENDL-3.2 (2020) | ENDF/B-VII.0 (2018) | JEFF-3.3 (2017) | BROND-3.1 (2016) | ENDF/B-VII.1 (2011) | JENDL-4.0 (2010) |
|----------|------------------|---------------------|-----------------|-----------------|-------------------|------------------|
| $^{235}$U (10 keV–) | 800 keV–: | (=JENDL-4.0) | (=ENDF/B-VII.1) | (= ROSTFOND-2010) | 40 keV–: | Maslov |
|          | Available works | 80–800 keV: | 40 keV–: | Maslov |
|          | 10 works (1975–1988), | with denser grid | –40 keV: | URR |
|          | –80 keV: | (=ENDF/B-VII.1) | | |
| $^{235}$U (10 keV–) | 75 keV–: | (=IAEA-2006) | (= ROSTFOND-2010) | 25 keV–: | IAEA-2006 |
|          | –75 keV: | 1 MeV–: | 1 MeV–: | IAEA-2006 |
|          | IAEA-2017 | | 1 MeV–: | IAEA-2006 |
|          | with denser grid | with denser grid | 149 keV–1 MeV: | IAEA-2006 |
|          | 149–500 keV: | 149 keV–1 MeV: | 149 keV: | URR |
|          | –149 keV: | (=ENDF/B-VII.1) | (=ENDF/B-VII.1) | URR |
| $^{235}$U (100 keV–) | 150 keV–: | (=CENDL-2) | (=ENDF/B-VII-1) | 1 MeV–: | IAEA-2006 |
|          | 500 keV–2 MeV: | (=IAEA-2017) | (=ENDF/B-VII.1) | 1 MeV–: | URR |
|          | IAEA-2017 | 500 keV–2 MeV: | 1 MeV–: | with denser grid |
|          | with denser grid | IAEA-2017 | | |
|          | 149–500 keV: | IAEA-2017 | | |
|          | –149 keV: | (=ENDF/B-VII.1) | | |
| $^{235}$Pu (10 keV–) | 40 keV–: | (=IAEA-2006) | (=JENDL-4.0) | 42 keV–: | (=ENDF/B-V) |
|          | –IAEA-2017 | 30 keV–: | 42 keV–: | (=ENDF/B-V) |
|          | –40 keV: | (=JENDL-4.0) | Available works | 42 keV–: | 40 keV–: |
|          | IAEA-2006 | | Available works | 40 keV–: | |
|          | with denser grid | (=JENDL-4.0) | | |
|          | 149–500 keV: | (=JENDL-4.0) | 42 keV–: | URR |
|          | –43 keV: | (=JENDL-4.0) | 42 keV–: | URR |
| $^{239}$Pu (100 keV–) | 6 MeV–: | (=ENDF/B-VII-1) | TALYS-1.4 | 43 keV–: | TALYS-1.4 |
|          | 200 keV–6 MeV: | 149–500 keV: | All available works | 43 keV: | 43 keV–: |
|          | 200 keV–6 MeV: | (=ENDF/B-VII.1) | –43 keV: | URR |
|          | 300 keV–6 MeV: | (=ENDF/B-VII.1) | | |
|          | 11 works (1966–1990) | 300 keV–6 MeV: | | |
|          | –40 keV: | (=JENDL-4.0) | | |
| October 2018: 2000 keV | 30 keV–: | (=JENDL-4.0) | 200 keV: | 200 keV: |
|          | 21 works (1955–1983) | 200 keV–6 MeV: | | |
|          | –30 keV: | (=ENDF/B-VII.1) | | |
| $^{241}$Pu (100 keV–) | 40 keV–: | (=ENDF/B-V) | 40 keV–: | 40 keV–: |
|          | 3 works (1970–1975) | 3 works (1970–1975) | 40 keV–: | |
| October 2018: 2000 keV | 10 works | 3 works (1970–1975) | 40 keV–: | |

*: Adoption of a preceding library without any modification. ~: Adoption of a preceding library with modifications. ?: Method/origin of the evaluation unknown.

URR: Unresolved resonance region. Works: Experimental works. IAEA: IAEA Neutron Data Standards. Poenitz/Fröhener: Poenitz/Fröhener’s evaluation. Maslov: Maslov’s statistical model calculation.
sections, but our experimental database adopts the measured ratios converted by the experimentalists to the absolute cross sections with the $^6$Li and $^{10}$B standard cross sections at the time, and therefore our evaluation may be more biased by the old standard cross sections.

Two other major differences in the SOK and GMA evaluations are (1) treatment of cross section ratio data, and (2) selection of the energy nodes.

- SOK linearizes the cross section ratio by logarithmic transformation while GMA linearizes the cross section by the first-order Taylor approximation (c.f. Eq. 13b of Ref [46]).
- GMA requires extrapolation of the originally reported experimental cross sections to an energy grid commonly chosen for all reactions (c.f. Fig. 4 of Ref [46]) while SOK performs fitting to Schmittroth’s roof function, which does not require the extrapolation neither common energy grid structure.

The GMA database has some spectrum averaged cross sections and they are utilized in fitting in evaluation for the IAEA Neutron Data Standards while the current evaluation uses spectrum averaged cross sections only for validations. It would be also worthwhile to mention that the GMA database often includes the numbers not reported by the experimentalist but estimated by the evaluators while our experimental database constructed for the SOK analysis is automatic conversion of the EXFOR library and solely based on the numbers provided by the authors except for (1) assignment of the correlation properties (e.g. uncorrelated or fully correlated) and (2) addition of a few constant uncertainties and correlations not explicitly written in the source articles and cannot be compiled in their EXFOR entries because of the EXFOR policy.

### 3. Experimental database

The experimental database is the main input to the present least-squares analysis. All experimental datasets [47–153] were taken from the EXFOR library without any changes unless otherwise noted in this section. When the uncertainty information written in the source article is missing in the EXFOR entry, we notified it to the Data Centre maintaining the EXFOR entry, and the Centre updated the EXFOR entry accordingly. Table 2 summarizes the number of datasets used for final fitting. A summary of all experimental datasets adopted in the present evaluation (e.g. EXFOR sub-entry number, first author, year of publication, laboratory, reference) is published elsewhere [154].

#### 3.1. Selection of datasets by energy and publication year

The lower boundary of the incident energy for the present evaluation was unchanged from JENDL-4.0 (i.e. 10 keV for $^{233,235}$U and $^{239,241}$Pu, and 100 keV for $^{238}$U and $^{240}$Pu) while the upper boundary was extended from 20 MeV to 200 MeV. All experimental datasets including data points in this energy range and published no earlier than 1970 ($^{233,238}$U and $^{239,240,241}$Pu) or 1980 ($^{235}$U) were extracted from the EXFOR Master File. We excluded the datasets digitized from article figure images, superseded by other datasets, and measured with neutrons from slowing-down time spectrometers and nuclear explosions.

#### 3.2. Exclusion of duplicated datasets

A dataset published in an article may be revised and published again. Usually the superseded dataset is flagged by SPSSDD in the EXFOR entry, and we can avoid double counting of the same measurement by excluding the flagged one. However, identification of two datasets from the same measurement was not always trivial. Two major examples are discussed below.

#### 3.2.1. Exclusion of duplicated datasets from Karlsruhe isochronous cyclotron

There are several EXFOR entries providing the $^{235,238}$U and $^{239}$Pu(n,f) cross sections measured by Cierjacks et al. at the Karlsruhe isochronous cyclotron. From this work, the $^{235,238}$U absolute cross sections and their ratio were published separately [109, 155] and compiled in EXFOR 20943 and 20409, respectively. Their relation was discussed after the NEANDC/NEACRP Specialists Meeting on Fast Neutron Fission Cross Sections of U-233, U-235, U-238, and Pu-239 (28–30 June 1976 Argonne National Laboratory) between the editors of the meeting proceedings (W.P. Poenitz and A.B. Smith) and Cierjacks, and a note was added to Ref. [155] to clarify that the ratio was derived from the absolute cross sections. Similarly, the $^{235}$U and $^{239}$Pu absolute cross sections and their ratio from this work were published separately [109, 128] and compiled in EXFOR 20786 and 20409, respectively.

#### Table 2. Number of experimental datasets of fission cross sections and their ratios for final fitting.

| Denominator | $^{233}$U | $^{235}$U | $^{238}$U | $^{239}$Pu | $^{240}$Pu | $^{241}$Pu |
|-------------|----------|----------|----------|-----------|-----------|-----------|
| unity       |          | 12       | 22       | 19        | 7         | 8         |
| $^{235}$U   | -        | -        | -        | -         | -         | -         |
| $^{239}$Pu  |          | 12       | -        | 19        | 13        | 4         |

*Note: Denominator: $^{233}$U, $^{235}$U, $^{238}$U, $^{239}$Pu, $^{240}$Pu, $^{241}$Pu. Numerator: $^{233}$U, $^{235}$U, $^{238}$U, $^{239}$Pu, $^{240}$Pu, $^{241}$Pu.*
for which an author confirmed that each of the Pu isotopes was measured only once in this experimental work and the 1976 and 1978 data should be based on the same raw data [156].

Finally, we adopted only the $^{238}\text{U}/^{235}\text{U}$ cross section ratio in EXFOR 20409.002 and the $^{239}\text{Pu}/^{235}\text{U}$ cross section ratio in EXFOR 20786.005 among several $^{238}\text{U}$ and $^{239}\text{Pu}$ datasets in these EXFOR entries, and discarded their absolute cross sections to be free from the n-p scattering reference cross section used for normalization.

### 3.2.2. Exclusion of duplicated data points from TUD-KRI collaboration

Another major complication was selection of the final results from the absolute cross sections measured with the associated particle method by the Technische Universität Dresden (TUD) and Kholpin Radium Institute (KRI). This question was introduced as an open problem in a review of the GMA database [157]. The tables of Ref. [52] show there are several measurements for the same target nuclide and incident energy in some cases, and this makes selection of the data points without double counting very difficult. We traced the history of the measurements at TUD, KRI and ZFK (Zentralinstitut für Kernforschung, Rossendorf) by reviewing all journal articles and reports compiled in CINDA (Comprehensive Index of Nuclear Reaction Data) [158], and selected the data points listed in Table 3 as inputs to our analysis. See Ref. [154] for more details.

### 3.3. Modification to EXFOR entries

Our guiding principle is to use the datasets in the official EXFOR entries without any further corrections. To utilize additional information provided by the authors but cannot be in the official EXFOR entries, we modified a few EXFOR entries for the present evaluation:

- $^{233,235,238}\text{U}$ and $^{239}\text{Pu}$ by Dushin et al. [52] (EXFOR 51001)

Prepared to collect the absolute fission cross sections measured by the associated particle method at KRI assuming that the KRI data points tabulated in Ref. [52] are the final ones (See also Table 3). The covariance matrices published in this reference were converted to the correlation coefficients, and used as inputs to our evaluation.

- $^{238}\text{U}/^{235}\text{U}$ by Poenitz et al. [113] (EXFOR 51002)

Prepared to merge three datasets EXFOR 10232.002, 003 and 004 to one dataset to include their correlation recorded by Poenitz in the GMA database entry #816 and #818.

- $^{238}\text{U}/^{235}\text{U}$ by Paradela et al. [100] (EXFOR 51005)

Prepared to merge two datasets EXFOR 23269.003 and 004 to one dataset to include their correlation due to use of the same sample.

- $^{235}\text{U}$ by Amaducci et al. [70] (EXFOR 51006)
Prepared to merge two datasets EXFOR 23453.002 and 003 to one dataset to include their correlation due to use of the same $^{235}$U fission counts.

- $^{233}$U and $^{239,241}$Pu by Blons et al. [58, 120, 152] (EXFOR 51007, 51008, 51009)

Prepared to average the high-resolution cross sections in EXFOR 20001.002, 20446.002, and 20484.002 to reduce the number of data points to 50 points per decade. Note that the two data points at the highest two energies in EXFOR 51008.002 ($^{233}$U averaged dataset) were removed due to the unreasonable energy dependence seen in the original dataset (EXFOR 20446.002).

- $^{235}$U by Merla et al. [74] (EXFOR 51010)

Prepared to utilize the information on the statistical uncertainties in a preliminary report [159] together with the data points compiled from the final report (EXFOR 22304.006).

### 3.4. Construction of experimental covariances

A critical step of the current evaluation is determination of the covariances of each experimental dataset. We used several approaches depending on the available information in the EXFOR entry and source article. A summary on the range and source of each partial uncertainty included in construction of the covariances is published elsewhere [154].

- Correlation coefficients in EXFOR

Correlation coefficients are explicitly given under the keyword COVARIANCE in the EXFOR entry for a few cases (EXFOR 13169.002 [91], 14498.002 [99], 22211.002 [142], 22282.003.1 and 006.1 [64], 41112.002 [75], 51001.002-005 [52], 51006.002 [70]) and they were directly taken as inputs to our fitting.

- Correlated and uncorrelated partial uncertainties in EXFOR

When the correlated and uncorrelated partial uncertainties are in the EXFOR entry separately, we used them for estimation of the correlation coefficients. The quadrature sum of the correlated and uncorrelated partial uncertainties exceeds the total uncertainty in EXFOR 23458.006 [140]. For this dataset, we discarded the uncorrelated partial uncertainty in the EXFOR entry, treated the total uncertainty in the EXFOR entry as uncorrelated, and combined it with the correlated partial uncertainty in the EXFOR entry.

- Correlated or uncorrelated partial uncertainty and total uncertainty in EXFOR

When the correlated or uncorrelated partial uncertainty is missing in the EXFOR entry but the total uncertainty is coded under the heading ERR-T in the EXFOR entry, we derived the missing partial uncertainty by subtracting the other partial uncertainty from the total uncertainty assuming the quadrature sum rule. The quadrature sum of the correlated or uncorrelated partial uncertainties exceeds the total uncertainty in some data points of seven datasets (EXFOR 10653.004 [107], 21764.004 [138], 22321.006 [90], 22698.005 [48], 23078.002-003 [71], 40506.002 [108]), and these data points were excluded from the evaluation. There is one more dataset creating the same problem in many points (EXFOR 22014.003 [65]), and we treated the uncertainty declared as the total uncertainty in the EXFOR entry as uncorrelated. The total uncertainty is absent for the data points below 10 keV in EXFOR 10267.002 [56], and these data points were discarded.

| Target  | EXFOR # | Unc. | Source of uncertainty |
|---------|---------|------|-----------------------|
| $^{233}$U | 13890.004 | 1.0 | Uncertainty due to normalization to the thermal value [200] (0.25% from thermal normalization +0.7% from point-wise uncertainty) |
| $^{233}$U | 51008.002 | 1.4 | Uncertainty in the thermal reference value [202]
| $^{238}$U | 13169.003.2 | 1.0 | Normalization uncertainty (minimum 1%, see 13169.002) |
| $^{240}$Pu | 40673.004 | 0.15 | Uncertainty in the target half-life (6357 ±10 yr) |
| $^{241}$Pu | 40673.005 | 1.4 | Uncertainty in the target half-life (14.4 ±0.2 yr) |
| $^{241}$Pu | 51009.002 | 1.5 | Uncertainty in the thermal reference value [202]
| $^{233}$U/$^{235}$U | 41432.003 | 0.74 | Uncertainty in the fissile nucleus number ratio (taken from a preliminary report of the same experiment [160]) |
| $^{239}$Pu/$^{235}$U | 20569.004 | 1.0 | Uncertainty in the sample mass (0.6% from $^{239}$Pu+0.8% from $^{235}$U) |

| Table 4. Normalization uncertainties not coded in the EXFOR entries but used in the current evaluation. ‘Unc.’ gives the uncertainty in %. |
Sometimes a fully correlated (overall normalization) partial uncertainty can be easily inferred from the article text even if it cannot be in the official EXFOR entries due to the EXFOR policy. When such information exists with an energy-dependent uncertainty in the EXFOR entry, we estimated the normalization uncertainty and stored it in an input file rather than modification of the EXFOR entry. The uncorrelated partial uncertainty was obtained by subtraction of the normalization uncertainty from the energy-dependent uncertainty in the EXFOR entry assuming the quadrature sum rule. Table 4 summarizes such normalization uncertainties estimated by us with their justifications.

- **Special cases**

The uncertainties due to statistics, detector efficiency and position are combined into one uncertainty in EXFOR 20618.003 [119], and it was treated as uncorrelated. The energy-dependent uncertainty without source specification in EXFOR 40483.002 [96] was assumed as uncorrelated, and the dataset was treated as a shape dataset without correlated partial uncertainties.

- **Other cases**

All datasets not belonging to the above-mentioned categories were excluded from the present evaluation.

In general, the lower boundary was adopted as a constant uncertainty when only a range is known for the partial uncertainty.

It is not trivial to estimate the correlation coefficient when a partial uncertainty is neither uncorrelated (e.g. statistical uncertainty) nor fully correlated (e.g. normalization uncertainty). Following ‘Occam’s Razor’ strategy [28], we treated all partial uncertainties other than those due to counting statistics (coded under the heading ERR-S or with the correlation flag U in EXFOR) as fully correlated uncertainties, namely our estimation gives the upper limit of the actual correlation coefficient. Presence of correlation between two datasets from the same experimental work was found in a few EXFOR entries [70, 100, 113], and we merged such datasets to a single dataset to take into account the known correlation appropriately (see Sect.3.3). Any two datasets in our experimental database were therefore treated as independent each other.

## 4. Least-squares fitting

The least-squares fitting was performed by SOK, which updated the prior estimates of the cross sections (taken from evaluated data libraries) by including the experimental dataset one-by-one from our experimental database.

### 4.1. Formalism

The SOK code adopts Schmittroth’s roof function [161] (Figure 1) as the model to express the logarithm of the cross section \( \Sigma(E) = \ln \sigma(E) \) by introducing \( n \) energy nodes between \( E_i \) and \( E_n \):

### Equation 1

\[
\Sigma(E) = \sum_{j=1}^{n} \Delta_j(E)
\]

with

### Equation 2

\[
\Delta_j(E) = \begin{cases} 
\frac{E-E_{j-1}}{E_j-E_{j-1}} & (E_{j-1} \leq E \leq E_j) \\
\frac{E_j-E}{E_j-E_{j+1}} & (E_j \leq E < E_{j+1}) \\
0 & \text{otherwise}
\end{cases}
\]

which is equivalent to fitting to the first-order B-spline function [15, 162]. The fitting parameter \( \Sigma_j = \ln \sigma_j \) is the logarithm of the evaluated cross section at \( E_j \). The logarithm of an experimental cross section at \( E_j \) \( (E_j \leq E < E_{j+1}) \) is related with the fitting parameters by

### Equation 3

\[
\Sigma^{\text{exp},j} = \Sigma_j \delta_j + \Sigma_{j+1} \delta_{j+1} - \ln a + \delta_i
\]

with the residual of fitting \( \delta_i \) and

### Equation 4

\[
\delta_j = \begin{cases} 
\frac{E_{j+1} - E_j}{E_{j+1} - E_j} - \frac{E - E_{j+1}}{E_{j+1} - E} & (E \leq E_j) \\
\frac{E - E_j}{E_{j+1} - E_j} - \frac{E_{j+1} - E}{E_{j+1} - E_j} & (E_{j+1} < E) \\
0 & (E_j \leq E < E_{j+1})
\end{cases}
\]

See Ref [22, 23] for further details about SOK such as the least-squares solution and treatment of the cross section ratio. The evaluated cross sections in the JENDL-4.0 library (below 20 MeV) and JENDL-4.0/HE library [163] (above 20 MeV) were adopted as the prior estimates of the parameters except for the \(^{233}\text{U}\) fission cross section above 20 MeV, which is not in the JENDL-4.0/HE library and the evaluation by Yabshits et al. [164] was adopted instead. Note that the high energy part of the fission cross sections in the JENDL-4.0/HE library is from the JENDL/HE-2007 library [165]. The uncertainties in all prior parameters were set to 50% without correlation among them.

In the present work, the original version of SOK used for JENDL-3.3 and JENDL-4.0 evaluations was slightly extended to treat shape datasets (i.e. datasets in arbitrary unit). The logarithm of an experimental cross section in arbitrary unit \( \Sigma^{\prime,\text{exp},j} \) may be related with the fitting parameters by

### Equation 5

\[
\Sigma^{\prime,\text{exp},j} = \Sigma_j \delta_j + \Sigma_{j+1} \delta_{j+1} - \ln a + \delta_i
\]

where \( a \) is an additional fitting parameter normalizing the cross section in the arbitrary unit to the absolute one and we took 1.0 ± 0.5 as its prior estimate. In addition to the dataset EXFOR 40483.002 (see Sect. 3.4), we also treated the \(^{233}\text{U}\) dataset in EXFOR 14529.002 [88] as a shape dataset excluding the normalization uncertainty (4.1%) since the dataset is originally normalized to IAEA Neutron Data Standards.
2006 (IAEA-2006) [1,2] at 130 MeV, and we would like to maintain our evaluation free from this normalization. The parameter $a$ and its uncertainty were estimated in the present least-squares analysis for normalization within the fission cross sections of the six nuclides. Such shape datasets are also included in the GMA database in the IAEA evaluation where normalization is done taking into account not only fission standards but also more fundamental standards of light nuclides, and one could expect more reasonable estimate of the normalization parameters than those estimated in the present evaluation.

It is obvious from the formalism that the evaluated cross sections at the lower and upper boundaries of the energy range for evaluation must be determined with the experimental data points not only inside but also outside of the energy range. Namely, we need extra energy nodes below the lower boundary and above the upper boundary [161]. In order to take into account this effect, we added a few extra nodes to include the data points of each dataset above 7 keV ($^{233,235}\text{U}, ^{239,241}\text{Pu}$) or 70 keV ($^{238}\text{U}, ^{240}\text{Pu}$) and below 250 MeV.

### 4.2. Revision of experimental database after preliminary fitting (LANSCE data)

Tovesson et al. published fission cross sections measured at LANSCE [59, 124, 166] for various target nuclides after JENDL-4.0 evaluation. They are very useful for the present evaluation since these measurements cover the neutron energy up to 200 MeV and compiled in the EXFOR library with the cross section ratios and energy-dependent partial uncertainties in general. Following their instruction [167], we initially constructed the correlation coefficients of these datasets assuming that the energy-dependent and independent ‘systematic’ uncertainties are fully correlated. This is consistent with our general procedure but it sometimes leads to very strong correlation coefficients and strange results as demonstrated in Figure 2. The result becomes more reasonable if we weaken the correlation by treating all partial uncertainties other than the normalization uncertainty as uncorrelated, and we adopted this procedure for all LANSCE datasets measured by Tovesson et al. (EXFOR 14271.003.1 and 006.1 [124], 14402.003 and 009 [59]). Note that we excluded their (1) $^{241}\text{Pu}/^{235}\text{U}$ dataset below 1 MeV (EXFOR 14271.006.1 [124]) and $^{241}\text{Pu}$ dataset (EXFOR 14271.005 [124]) because they do not agree with almost all data points of the other datasets within the error bars between 20 keV and 800 keV as shown in Figure 3, and (2) $^{239,240}\text{Pu}$ datasets (EXFOR 14223.002 [166] and 14271.002 [124]) because their ratios to $^{235}\text{U}$ are not available from the authors. A theoretical study [168] concludes that the most of the discrepant $^{241}\text{Pu}$ datasets between 0.1 and 2 MeV can be covered by changing the fission barrier height of $^{242}\text{Pu}$ by only 150 keV and one cannot exclude a discrepant dataset by such theoretical consideration.

### 5. Results

The number of the experimental data points used for the present evaluation was 7379, and the number of the fitting parameters was 497 including two
fitting parameters for shape data normalization (EXFOR 14529.002 and 40483.002). With these parameters, the reduced chi-square (chi-square divided by the degree-of-freedom) is 4.00 if we compare the experimental database with the evaluated cross sections in the whole energy range for fitting (7 or 70 keV to 250 MeV). The reduced chi-square slightly increases to 4.45 if we lower the upper energy boundary from 250 MeV to 20 MeV, which is still smaller than the reduced chi-square

![Image](image1.png)

Figure 2. Fitting to the LANSCE $^{241}$Pu(n,f)/$^{235}$U(n,f) cross section ratio (EXFOR 14271.006.1) [124] with strong correlation (i.e. all partial uncertainties other than the statistical uncertainty are treated as fully correlated) and weak correlation (i.e. all partial uncertainties other than the normalization uncertainty are treated as uncorrelated). Note that the experimental data points below 1 MeV were discarded in the present evaluation.

![Image](image2.png)

Figure 3. Comparison of the LANSCE $^{241}$Pu(n,f) cross section (EXFOR 14271.005) and $^{241}$Pu(n,f)/$^{235}$U(n,f) cross section ratio (EXFOR 14271.006.1) [124] with other datasets. The cross section ratio from LANSCE is normalized to the ratio at 25.3 meV by Tovesson et al. The absolute cross section is converted from the ratio by using the ENDF/B-VII library by Tovesson et al.
calculated with the same experimental database and the prior cross sections (JENDL-4.0) in the same energy range (6.57). The newly evaluated (posterior) cross sections from final fitting are plotted with the prior cross sections and experimental cross sections in Figures 4-16. The band accompanying the newly evaluated cross section in each figure shows the external uncertainty in the evaluated cross section modelled by the roof function. See Sect.5.6 for more details.

5.1. Comparison with JENDL-4.0 and IAEA Neutron Data Standards 2017

Here, we discuss comparison of the newly evaluated cross sections with the cross sections in the JENDL-4.0 library and IAEA Neutron Data Standards 2017 (IAEA-2017). The JENDL-4.0 cross sections were evaluated by the SOK code but with another experimental database, which was constructed from EXFOR by a different approach and also does not include a number of new experimental datasets. The IAEA-2017 cross sections were evaluated for $^{235,238}$U and $^{239}$Pu by the GMA code as described in Sect. 2.

Figure 17 shows difference of the newly evaluated cross sections from the JENDL-4.0 cross sections in the 70-group structure defined in the JFS-3 (JAERI-Fast Set Ver.3) format [169, 170]. The group-wise cross sections were calculated by replacing the fission cross sections in the JENDL-4.0 library with the newly evaluated ones in the ENDF-6 format by DeCE [171] and processing by PREPRO2019 [172]. Roughly speaking, the change from JENDL-4.0 is within 4% for $^{241}$Pu, 3% for $^{233}$U and $^{240}$Pu, and 2% for $^{235}$U and $^{239}$Pu. For $^{238}$U, the change is small (within 1%) above 1 MeV but large in the sub-threshold region.

We observe collective increase of the cross sections of $^{233}$U, $^{235}$U and $^{239}$Pu in the 24th group (24.8 keV to 31.8 keV). Amaducci et al. [70] report that JENDL-4.0 underestimates the $^{235}$U cross section from their measurement about 4 and 5% in 30–60 and 60–100 keV region, respectively. Figure 17 shows that the newly evaluated $^{235}$U cross section is also increased by 2–4% from the JENDL-4.0 cross section in the 22th to 24th group (24.8 to 52.5 keV) and less increase in the 19th to 20th group (67.4–111 keV).

Figure 18 shows difference of the newly evaluated cross sections from the IAEA-2017 cross sections in the JFS-3 70-group structure. They agree within 2% for all three nuclides with some exceptions. The collective increase in the $^{235}$U and $^{239}$Pu cross sections in the 24th group (24.8–31.8 keV) seen in comparison with the JENDL-4.0 library appears again in this comparison. We performed a trial fit excluding some datasets, which seem relevant to this deviation such as $^{233}$U by Calviani et al. (23072.009 [47]), $^{235}$U by Amaducci et al. (51006.002 [70]) and $^{239}$Pu by Blons et al (51007.002 [120]), but it did not eliminate the cross section structures seen in this energy region. Collective decrease in the $^{233}$U and $^{239}$Pu cross sections in the 18th group (111–143 keV) is also commonly seen in the

![Figure 4](image-url) 233U fission prior and posterior cross sections with the experimental cross sections used for evaluation [47–58]. The prior cross section is taken from JENDL-4.0 (below 20 MeV) and Yavshits’ evaluation (above 20 MeV).
Table 5. Californium-252 spontaneous fission neutron spectrum averaged cross sections (mb).

|       | \(^{237}\text{U}\) | \(^{238}\text{U}\) | \(^{239}\text{U}\) | \(^{239}\text{Pu}\) | \(^{240}\text{Pu}\) | \(^{241}\text{Pu}\) |
|-------|------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Present | 1900             | 1223            | 316             | 1800            | 1340            | 1606            |
| Grundl [175] | 1893 ± 48          | 1216 ± 19        | 326 ± 6.5       | 1824 ± 35         | 1337 ± 32         | 1616 ± 80         |
| Mannhart [177] | 1210 ± 15             | 325.7 ± 5.3      | 1812 ± 25      |                 |                 |                 |

Figure 5. \(^{233}\text{U}/^{235}\text{U}\) fission prior and posterior cross section ratios with the experimental cross section ratios used for evaluation [59–69]. The prior cross section is taken from JENDL-4.0 (below 20 MeV), Yavshits’ evaluation (above 20 MeV, \(^{233}\text{U}\)) and JENDL-4.0/HE (above 20 MeV, \(^{235}\text{U}\)).

Figure 6. \(^{235}\text{U}\) fission prior and posterior cross sections with the experimental cross sections used for evaluation [52–65]. The prior cross section is taken from JENDL-4.0 (below 20 MeV) and JENDL-4.0/HE (above 20 MeV). In the legends of Amaducci et al.’s datasets, \(^6\text{Li}\) and \(^{10}\text{B}\) denote the cross sections normalized with the \(^6\text{Li}(n,t)^{4}\text{He}\) and \(^{10}\text{B}(n,\alpha)^{7}\text{Li}\) standard cross sections, respectively.
Figure 7. $^{238}$U fission prior and posterior cross sections with the experimental cross sections used for evaluation [52, 71, 74, 87–96]. The prior cross section is taken from JENDL-4.0 (below 20 MeV) and JENDL-4.0/HE (above 20 MeV).

Figure 8. $^{238}$U/$^{233}$U fission prior and posterior cross section ratios with the experimental cross section ratios used for evaluation [97]. The prior cross section is taken from JENDL-4.0 (below 20 MeV), JENDL-4.0/HE (above 20 MeV, $^{238}$U) and Yavshits’ evaluation (above 20 MeV, $^{233}$U).

comparison with the JENDL-4.0 and IAEA-2017. The difference in the $^{238}$U cross section in the threshold region (1–2 MeV) is also remarkable, and this could be due to the small bump at $\sim 1.2$ MeV visible in some high-resolution experimental datasets (e.g. EXFOR 23269.007 measured by Paradela et al. [100]).

5.2. Validation by californium-252 spontaneous fission neutron spectrum averaged cross sections

As a validation of the newly evaluated cross sections in the prompt fission neutron energy region, we derived the californium-252 (Cf-252) spontaneous fission neutron spectrum averaged cross sections (SACS) from the
newly evaluated cross sections, and compared them with those derived from the cross sections in the other evaluated data libraries and experimental ones. We updated the JENDL-4.0 files by replacing the fission cross sections with the newly evaluated ones in the ENDF-6 format by using DeCE, and converted the cross sections in the updated files to the SAND-II 725 energy group structure by PREPRO2019, which were then averaged over the Cf-252 spontaneous fission neutron spectrum evaluated by Mannhart [173, 174] and compiled in the IRDFF-II library in the same group structure.

Figure 19 shows the ratios of the evaluated SACS to the SACS measured by Grundl and Gilliam [175] for the present evaluation as well as the JENDL-4.0, ENDF/B-VIII.0, ENDF/B-VII.1 [176], JEFF-3.3 and CENDL-3.2 evaluations. In addition to the SACS derived from these evaluations, the SACS recommended by Mannhart
Figure 11. $^{239}\text{Pu}/^{235}\text{U}$ fission prior and posterior cross section ratios with the experimental cross section ratios used for evaluation [61, 63, 66, 69, 73, 84, 103, 105, 124–133]. The prior cross section is taken from JENDL-4.0 (below 20 MeV) and JENDL-4.0/HE (above 20 MeV).

Figure 12. $^{240}\text{Pu}$ fission prior and posterior cross sections with the experimental cross sections used for evaluation [80, 134–139]. The prior cross section is taken from JENDL-4.0 (below 20 MeV) and JENDL-4.0/HE (above 20 MeV).

[177] are also shown for $^{233}\text{U}$, $^{235}\text{U}$ and $^{239}\text{Pu}$. The SACS from the present evaluation are also summarized in Table 5 along with those measured by Grundl et al. and recommended by Mannhart. This figure shows that a similar degree of agreement with the measured and recommended SACS is achieved by the present and JENDL-4.0 evaluation. The SACS from the present evaluation agrees with the measured and recommended SACS within error bars except for $^{238}\text{U}$. We tried various fitting (e.g. by changing the energy grid structure in the threshold region for $^{238}\text{U}$), but it was not possible to improve their agreement. The underestimation of the
measured and recommended SACS for $^{238}$U is seen not only in JENDL evaluations but also in many other evaluations. Among the ENDF/B evaluations, ENDF/B-VII.1 SACS is close to the present SACS while the ENDF/B-VIII.0 SACS is within the error bar of the SACS measured by Grundl and Gilliam, and also agrees with the lower boundary of Mannhart’s recommended SACS.

Since the Cf-252 SACS of $^{238}$U has large sensitivity with respect to the energy-dependent cross sections around 2 MeV, we compared the present $^{238}$U point-wise cross section with those in ENDF/B-VII.1 and ENDF/B-VIII.0 in Figure 20, where all absolute experimental cross sections compiled in the EXFOR library published no earlier than 1970 are also plotted. This figure shows the ENDF/B-VII.1 and ENDF/B-VIII.0 SACS are close to each other and ENDF/B-VII.2.

Figure 13. $^{240}$Pu/$^{235}$U fission prior and posterior cross section ratios with the experimental cross section ratios used for evaluation [125, 128, 138, 140–148]. The prior cross section is taken from JENDL-4.0 (below 20 MeV) and JENDL-4.0/HE (above 20 MeV).

Figure 14. $^{240}$Pu/$^{239}$Pu fission prior and posterior cross section ratios with the experimental cross section ratios used for evaluation [126, 146]. The prior cross section is taken from JENDL-4.0 (below 20 MeV) and JENDL-4.0/HE (above 20 MeV).
Figure 15. $^{241}$Pu fission prior and posterior cross sections with the experimental cross sections used for evaluation [121, 123, 135, 136, 139, 149–152]. The prior cross section is taken from JENDL-4.0 (below 20 MeV) and JENDL-4.0/HE (above 20 MeV).

Figure 16. $^{241}$Pu/$^{235}$U fission prior and posterior cross section ratios with the experimental cross section ratios used for evaluation [67, 124, 153]. The prior cross section is taken from JENDL-4.0 (below 20 MeV) and JENDL-4.0/HE (above 20 MeV).

B-VIII.0 gives much higher cross section than the ENDF/B-VII.1 and present evaluation between 1.7 and 2.0 MeV. In this energy region, the ENDF/B-VIII.0 cross section is higher than the majority of the experimental cross sections, but more consistent with the recently published cross sections from an absolute measurement at National Physical Laboratory (NPL) with neutron flux determined by a long counter [87]. The ENDF/B-VIII.0 cross section is based on IAEA-2017 which difference from the present evaluation in this energy region is visible in Figure 18.
5.3. Validation by $\Sigma\Sigma$ spectrum averaged cross sections

The neutron field of a coupled thermal/fast uranium and boron carbide spherical assembly $\Sigma\Sigma$-ITN (Bucharest) was developed for benchmark of the fast neutron dosimetry [178]. Spectrum averaged cross sections of various dosimetry reactions were measured at this facility [178–180], and have been utilized for validation of the dosimetry cross section libraries such as IRDF-2002 [181] and IRDFF-II [182]. The $\Sigma\Sigma$ neutron spectrum (average energy of 730 keV [32]) is softer than the Cf-252 spontaneous fission neutron spectrum, and we calculated the newly evaluated cross sections averaged over the $\Sigma\Sigma$ spectrum for validation complementary to the Cf-252 SACS validation. The $\Sigma\Sigma$ neutron spectrum tabulated by Fabry [183] in a 135 energy group structure converted to the SAND-II 725 energy group structure [184] was used for tabulation of the spectrum averaged cross sections for the IRDFF-II full summary report [182], and we also used the same 725 energy group spectrum for our validation. The evaluated cross sections updated from JENDL-4.0 in the 725 energy group structure were prepared by DeCE and PREPRO2019 as mentioned in Sect. 5.2.

Figure 17 shows the ratios of the evaluated SACS to the SACS measured at $\Sigma\Sigma$-ITN by Gârlea et al. [178] for the present evaluation as well as the JENDL-4.0, ENDF/B-VIII.0, ENDF/B-VII.1, JEFF-3.3, and CENDL-3.2 evaluations. The SACS from the present evaluation are also summarized in Table 6 along with those measured by Gârlea et al. The figure shows that
the spectrum averaged cross sections of all evaluations agree with the measured values within the experimental error bar, which is originated from statistics (about 0.5%), sample mass (1.6% to 3.0%), run-to-run monitor level, and corrections. Gârlea et al. use their cross section ratios to the $^{235}\text{U}$ cross section (1512 ± 53 mb) for comparison with other $\Sigma \Sigma$ measurements. Similarly, we also added the ratios from the present evaluation and libraries to Figure 21 for comparison with their experimental ratios. It shows the ratios of the cross sections to the $^{235}\text{U}$ cross section from the present evaluation also agree with the measured ones.

### 5.4. Validation by small-sized LANL fast system criticalities

Figure 17 shows the $^{235}\text{U}$ and $^{239}\text{Pu}$ cross sections from the present evaluation are higher than the JENDL-4.0 cross sections in the 13rd to 17th groups (143–498 keV). It is known that the criticalities of the small-sized LANL fast systems such as Godiva and Jezebel are sensitive to the $^{235}\text{U}$ and $^{239}\text{Pu}$ cross sections in this energy region, and one can expect the criticalities calculated with the newly evaluated cross sections are much higher than those calculated with the JENDL-4.0 cross sections unless other data (e.g. capture cross sections, prompt fission neutron multiplicities and spectra) are readjusted. As the cross sections of this energy region are important for fast reactor application, the criticalities of nine small-sized LANL fast systems (Jezebel-23, Flattop-23, Godiva, Flattop, Big-Ten, Jezebel, Jezebel-240, Flattop-Pu and Thor) were calculated by Yasunobu Nagaya (JAEA) with the original JENDL-4.0 library and its update prepared by DeCE. The neutron transport calculations were performed with the Japanese continuous-energy Monte Carlo code MVP Version 3 [185].

Figure 22 compares the C/E values of the criticalities calculated with the original and updated JENDL-4.0 cross sections. The changes in the C/E values of the criticalities due to update from JENDL-4.0 are similar to those seen in the Cf-252 SACS. Namely, the cross section update leads to decrease in the C/E values for the $^{233}\text{U}$ fueled systems while to increase of the C/E values for the $^{235}\text{U}$ and $^{239}\text{Pu}$ fueled systems. The tendencies for the $^{235}\text{U}$ and $^{239}\text{Pu}$ fueled systems are also understandable from the increase of their cross sections in the 150–450 keV region seen in Figure 17. The C/E value of Big-Ten is improved with the current evaluation but it is still considerably low. The JENDL-4.0 benchmark summary [186] mentions the Big-Ten C/E value is sensitive to $^{238}\text{U}$ inelastic scattering cross section. But the fission cross section of our evaluation lower than 100 keV could be also partly responsible to the low Big-Ten C/E value since the Big-Ten neutron spectrum is softer than the spectra of the other $^{235}\text{U}$ fueled systems. Figure 18 shows our $^{235}\text{U}$ cross section is systematically lower than IAEA-2017 (~ ENDF/B-VIII.0) below 100 keV.

We also analyzed the low C/E values for the Jezebel-233 and Flattop-233 by using the sensitivities of the cross sections with respect to the criticalities calculated by a deterministic reactor physics code CBZ [187]. It indicates that the decrease in their criticalities is due to update of the $^{233}\text{U}$ cross section around 2 MeV from JENDL-4.0.

### 5.5. High energy cross sections

Some JENDL special purpose libraries include the $^{235,238}\text{U}$ and $^{239,240,241}\text{Pu}$ fission cross sections above 20 MeV evaluated by an approach completely different from the present approach. This time we evaluated the fission cross sections of the six nuclides above 20 MeV for the JENDL general purpose library for the first time. The prior $^{235,238}\text{U}$ and $^{239,240,241}\text{Pu}$ cross sections taken from the JENDL-4.0/HE library are those calculated by the GNASH code [188] and slightly changed to fit to the available experimental datasets according to the descriptions in their ENDF-6 files. The prior $^{235}\text{U}$ cross section evaluated by Yavshits et al. is theoretical one obtained by their multiconfiguration fission approach. Most of the high energy experimental datasets adopted in the present evaluation were not available when these prior cross sections were evaluated. Here, we discuss comparison of the high energy cross sections from the present evaluation with their prior cross sections as well as the cross sections from time-of-flight measurements.

#### 5.5.1. $^{233}\text{U}$

Figures 4 and 5 show that the newly evaluated $^{233}\text{U}$ high energy cross section is systematically lower than the prior cross section evaluated by Yavshits et al. The two experimental $^{233}\text{U}/^{235}\text{U}$ cross section ratios measured by Tovesson et al. and Shcherbakov et al. are consistent each other in the high energy region. The number of target atoms based on sample specifications is used by Tovesson et al. while the ratio measured by Shcherbakov et al. is normalized to the JENDL-3.2 cross section ratio at 1.75–4.0 MeV.
5.5.2 $^{235}$U

Figure 6 shows that the newly evaluated high energy cross section is very close to the JENDL-4.0/HE cross section. Probably, the JENDL-4.0/HE cross section largely relies on the cross section measured by Lisowski et al. though its use is not described in the JENDL-4.0/HE data file. The newly evaluated high energy absolute cross sections of not only $^{235}$U but all nuclides strongly depend on this Lisowski et al’s measurement. For example, we observe influence of the structure around 50 MeV in this $^{235}$U measurement on the newly evaluated cross sections of other nuclides (e.g. Figures 10 and 12). The high-energy cross section should be reviewed again when the $^{235}$U cross section from 10 MeV to 1 GeV measured relative to n-p scattering at the CERN n_TOF facility [189] is published and added to the EXFOR library.

5.5.3. $^{238}$U

Figures 7 and 9 show that the newly evaluated $^{238}$U high energy cross section is close to the JENDL-4.0/HE cross section. Its data file describes that the evaluation considered three measurements [90, 190, 191], among which the second and third ones are most probably from the measurements by Lisowski et al. and Shcherbakov et al adopted by us. Major differences are seen among the high energy experimental ratios, and we plotted in Figure 23 these experimental and prior (JENDL-4.0 and JENDL-4.0/HE) ratios relative to the ratio from the present evaluation. The JENDL-4.0/HE ratio is between the two ratios measured by Lisowski et al. and Shcherbakov et al, and the situation is similar in the present evaluation. Among the experimental ratios newly considered in the present evaluation, the fission ionization chamber (FIC) dataset measured by Paradela et al. (EXFOR 23269.002) is close to the present evaluation while the present evaluation is close to or even below the lower boundaries of the error bars of the other new ratios measured by Paradela et al. and Tovesson et al. Note that Shcherbakov et al. use the threshold method [192] instead of sample quantification for overall normalization of their ratio.

5.5.4. $^{239}$Pu

Figures 10 and 11 show that the newly evaluated $^{239}$Pu high energy cross section is significantly lower than the JENDL-4.0/HE cross section. Unlike the $^{238}$U/$^{235}$U case, we observe the JENDL-4.0/HE ratio is largely influenced by the ratio measured by Shcherbakov et al. and not by Lisowski et al. The ratio from the present evaluation agrees with the ratio measured by Lisowski et al. which is most probably not considered in the JENDL-4.0/HE evaluation. Figure 23 shows that the ratio from the present evaluation is close to the upper boundary of the error bars of the ratio measured by Tovesson et al. in general, but systematically lower than the ratio measured by Shcherbakov et al. and Staple et al. The ratios measured by Tovesson et al. and Shcherbakov et al. are normalized to the thermal cross section ratio and the JENDL-3.2 library at 1.75–4.0 MeV, respectively, while Staple et al. quantify the target atoms by alpha spectrometry. The IAEA-2017 evaluation summary [3] mentions a preliminary result of a very accurate fission cross section ratio measurement by a time projection chamber of the NIFPTE collaboration (not in EXFOR) in excellent agreement with IAEA-2006, and we expect the newly measured ratio is closer to the ratio measured by Lisowski rather than the ratios measured by Shcherbakov et al. and Tovesson et al. (See Fig. 37(c) of Ref. [3]).

5.5.5. $^{240}$Pu

Figures 12 and 13 show that the newly evaluated $^{240}$Pu high energy cross section is close to the JENDL-4.0/HE cross section in general. The ratios measured by Laptev et al. and Staples et al. are consistent with the new evaluation. The ratio measured by Laptev et al. is normalized to IAEA-2006 at 1, 5 and 10 MeV while Staple et al. quantify the target atoms by alpha spectrometry.

5.5.6. $^{241}$Pu

Figures 15 and 16 show the cross section from the present evaluation is systematically lower than the JENDL-4.0/HE evaluation. We observe in Figure 16 that the current evaluation adopts the shape of the ratio measured by Tovesson et al. at the high energy region but its overall normalization is more consistent with the ratio measured by Fursov et al. between 1 and 10 MeV.

5.6. Uncertainty and correlation

Figure 24 shows the uncertainties in the fitting parameters $\{\sigma_j\}$ in the roof function expression. The uncertainty in the evaluated cross section at any energy may be obtained by propagation from the uncertainties in $\{\sigma_j\}$ according to the model function. Alternatively, the uncertainty in the group-wise cross section at the energy interval $[E_j, E_{j+1}]$ may be obtained by fitting with the rectangular function

$$\Delta_\sigma(E) = \begin{cases} 1 & (E_j \leq E < E_{j+1}) \\ 0 & \text{otherwise} \end{cases}$$

and we evaluated the uncertainty in the cross section from the present evaluation by this approach since the covariance of the group-wise cross section can be accommodated in the ENDF-6 format. By fitting with the rectangular function, we obtained the fitting parameters ( = group-wise cross sections) with the reduced chi-square of 10.3. The reduced chi-square with the roof function expression is smaller (4.00),
Figure 19. Californium-252 spontaneous fission neutron spectrum averaged cross sections relative to those measured by Grundl and Gillam [175] for the present evaluation, JENDL-4.0, ENDF/B-VIII.0, ENDF/B-VII.1, JEFF-3.3 and CENDL-3.2 evaluations as well as Mannhart’s recommendation [177]. Note that ENDF/B-VIII.0 adopts JENDL-4.0 for $^{233}$U, and JEFF-3.3 adopts JENDL-4.0 for $^{241}$Pu.

Figure 20. Comparison of the $^{238}$U(n,f) cross sections from the present evaluation with the evaluated cross sections in ENDF/B-VIII.0 and ENDF/B-VII.1 as well as absolute cross sections in the EXFOR library compiled from the articles published no earlier than 1970. The solid circles show the data points from a recent (2017) absolute measurement at NPL [87].

and it indicates the roof function is more adequate for modelling of the energy dependence of the cross sections. The uncertainty in the group-wise cross section from the rectangular function expression is shown in Figure 24. The figure shows the best precision of about 1% ($^{235,238}$U), 1.5% ($^{233}$U, $^{239,240}$Pu) or 2.5% ($^{241}$Pu) is achieved around 2 to 3 MeV in the rectangular function expression. The figure also indicates presence of the large uncertainties for all nuclides in 50–250 keV in the roof function expression, where the uncertainty in our $^{235}$U cross section is close to the uncertainty reported by the most recent measurement by Amaducci et al. [70]. Few $^{235}$U experimental data-sets were usable for our analysis in this energy region,
and our evaluation could be improved for all six target nuclides if additional well-documented new \( ^{238} \text{U} \) cross sections become available in this energy region.

Note that the reduced chi-square higher than 1 indicates the uncertainty from the least-squares fitting (internal uncertainty) underestimates the uncertainty expected from the actual discrepancy of the experimental datasets (external uncertainty), and we converted the internal uncertainty to the external uncertainty by multiplying the internal uncertainty by the square root of the reduced chi-square. All uncertainties plotted in Figure 24 are the external
Figure 23. The $^{238}$U/$^{235}$U and $^{239}$Pu/$^{235}$U cross section ratios from measurements by Paradela et al. [100], Tovesson et al. [59, 124], Shcherbakov et al. [61], Lisowski et al. [73] and Staples et al. [125] (symbol) as well as the prior (JENDL-4.0 and JENDL-4.0/HE) cross sections (solid line) relative to the ratios from the present evaluation. The EXFOR 23269.003 and 23269.004 datasets by Paradela et al. are from two configurations of the same sample and compiled together in our experimental database as a single dataset (EXFOR 51005.002).

ones. We are aware that a shortcoming of this approach is treatment of all experimental data points of the various reactions and energies equally [193]. The JENDL-3.3 evaluators consider the uncertainty obtained by their evaluation to be too small probably due to unknown systematic uncertainties of the measurements [22]. But the large chi-square value may be also originated from a bias effect (missing correction). ‘Unknown influences on a measurement result can, obviously, not be taken into consideration and can therefore not be included in an uncertainty. … Not correcting does not cause a systematic uncertainty but a systematic deviation, i.e. just a wrong result’ [194]. We consider that high quality evaluation can be achieved by use of experimental datasets which pay attention not only to higher precision (e.g. by improving uncertainties) but also to higher accuracy (e.g. by identifying overlooked bias effects) [195].
Figure 24. External uncertainties in the fitting parameters in the roof function and rectangular function expressions. The uncertainty in the parameter in the rectangular function expression is equal to the uncertainty in the group-wise cross section. The horizontal dashed line indicates best achievable precision for each nuclide. The additional histogram (thin solid line) between 50 keV and 160 keV of the $^{235}$U panel shows the uncertainty in the cross section measured by Amaducci et al. [70].

Figure 25 compares the uncertainties from the present evaluation in the rectangular function expression with those in IAEA-2017 evaluation. The latter uncertainties are for the group-wise cross sections compiled in the ENDF-6 format. The upper part (a) of the figure is for the final uncertainties of the evaluations, namely the external uncertainties for the present evaluation and the uncertainties including the unrecognized systematic uncertainty (USU) for the IAEA evaluation. The lower part (b) of the figure is for the internal uncertainties for the present evaluation and the uncertainties excluding the USU for the IAEA evaluation. The USU is estimated to be 1.2% [3] for all three nuclides and its influence on the uncertainty in the IAEA-2017 cross section is small in the figure. The IAEA evaluation introduces in the GMA database an additional uncertainty component to outlying experimental data and it brings a reduced chi-square closer to 1, and it is included in the IAEA cross section uncertainties in the upper and lower part of the figure. Two evaluations show similar final precision except for 100–200 keV region and a few groups in the 30–60 keV region, where the uncertainty from the present evaluation shows strong energy dependence but it is rather constant in the IAEA evaluation. The lower part of the figure shows that the uncertainty from the present evaluation is slightly lower than the IAEA evaluation if we do not enlarge the uncertainty estimated by the SOK by the square root of the reduced chi-square. Note that the groups of the present evaluation are wider than those of the IAEA evaluation (the number of groups between 10 keV and 200 MeV is about 80 and 140 in the present and IAEA evaluation, respectively), and therefore the comparison in the uncertainties on this figure must be done with caution.

Figure 26 shows the correlation coefficients between the evaluated cross sections (fitting parameters) between the energy groups and target nuclides in the rectangular expression. We observe presence of the strong correlation between any two target nuclides at the same incident energy except for $^{238}$U in the subthreshold fission region (below $\sim$ 1 MeV).

6. Summary
The fission cross sections of $^{233,235,238}$U and $^{239,240,241}$Pu were evaluated by using the simultaneous least-squares fitting code SOK for the JENDL-5 library. The evaluated cross sections were obtained in the energy range of 10 keV ($^{233,235}$U, $^{239,241}$Pu) or 100 keV ($^{238}$U, $^{240}$Pu) to 200 MeV. The cross sections in the high energy region (20–200 MeV) were evaluated for the JENDL general purpose library for the first time. Each EXFOR entry relevant to our evaluation was reviewed against the source article, especially for the uncertainty
information, and the EXFOR entry was updated by the originating Data Centre when necessary. Also special attention was paid during construction of our experimental database to exclude double counting of the information from the same experimental work. The experimental datasets compiled in the EXFOR entries with the information sufficient for covariance matrix construction were converted to the input format of SOK.
with a few manipulations such as elimination of some data points and addition of normalization uncertainty inferred from the source article.

The outputs from the least-squares fitting code SOK were adopted as the evaluated cross sections without any further corrections. The changes in the obtained evaluated cross sections from those in the JENDL-4.0 library are within 4% (241Pu), 3% (233U, 240Pu), or 2% (235U, 239Pu). The best precisions of the group-wise cross sections were achieved around 2 to 3 MeV, where the external uncertainties are 1% (235,238U), 1.5% (233U, 239Pu) or 2.5% (241Pu).

The californium-252 spectrum averaged cross sections were calculated from the evaluated cross sections, and compared with those measured by Grundl et al. and recommended by Mannhart. The comparison shows reasonable agreement except for 238U, for which our new evaluation could underestimate the actual cross section in the energy region around 2 MeV. The newly evaluated cross sections averaged over the ΣΣ neutron spectrum agree with those measured by Gârlea et al. for the 233,235,238U and 239Pu cross sections especially when the comparison is done for the ratios to the 235U cross section. A benchmark calculation performed for small-sized LANL fast system criticalities by MVP shows a reasonable agreement except for two 233U fueled systems and Big-Ten.

The final result of the present evaluation (SOK 20210404) was submitted for preparation of the JENDL-5 library. The JENDL-5 library would become the most up-to-date data library in terms of our experimental knowledge of the fission cross sections of the six target nuclides in the fast neutron region. Not only the JENDL project but also other data library projects may benefit from the uncertainty information added from the source articles to the EXFOR entries during the present evaluation.

Improvement of the 240Pu fission cross section between 0.5 and 5 MeV and the 241Pu fission cross section between 9 keV and 1 MeV are required to meet the target accuracy for the core and fuel cycle of a wide range of innovative systems [196, 197], and their target accuracies in the energy region of the present evaluation are 2 to 3% for fast reactor systems such as sodium-cooled fast reactor (SFR), gas-cooled fast reactor (GFR) and lead-cooled fast reactor (LFR) according to the NEA High Priority Request List (HPRL) [198]. The newly obtained evaluation cross sections do not satisfy this requirement, and further measurements and reevaluation are necessary. The present evaluation also shows relatively high uncertainty in 100–300 keV, and an additional measurement of the 235U cross section in this region would improve the precision of the newly evaluated cross sections not only for 235U but also for other target nuclides.

Notes

1. This summary overwrites the list of the EXFOR data-sets in MF1 MT451 of the JENDL-5 library ENDF-6 file. The experimental database in an ASCII file is available as a Supplemental Material.
2. A single ASCII file collecting all up-to-date EXFOR entries maintained by the IAEA Nuclear Data Section [199].
3. EXFOR entry numbers starting from 5 are introduced to distinguish the modified EXFOR entries from the official EXFOR entries. An ASCII file collecting these modified EXFOR entries is available as a Supplemental Material.
4. A video (animated GIF file) recording the data update in chronological order of experimental works is available as a Supplemental Material.
5. The evaluated cross sections in an ASCII file are available as a Supplemental Material.
6. Gubler et al. [49] adopt the 8.1-to-17.6 eV cross section integral of 965.2 eV-b determined by Wagemans et al. (Table 1 of Ref. [200]), which is from their point-wise cross sections normalized to the thermal cross section of 531.14 b ± 0.25%. The uncertainty in the cross section integral originated from the energy dependence of the point-wise cross section is not mentioned by Wagemans et al. We estimated it to 0.7% by propagating Wagemans’ point-wise uncertainty in EXFOR 22080.002 to the cross section integral.
7. Blons et al. [201] adopt the 8.32-to-101.2 eV resonance integral of 168.31 b evaluated by James [202]. The uncertainty in the resonance integral (1.4%) was estimated by us by propagating the uncertainty in each resonance integral in Table 1 of Ref. [202].
8. Blons et al. [201] adopt the 20-to-70 eV cross section integral of 2367.5 eV-b evaluated by James [202]. The uncertainty in the cross section integral (1.5%) was estimated by us by propagating the uncertainty in each group-wise cross section in Table IV of Ref. [202].

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References

[1] International Atomic Energy Agency. International evaluation of neutron cross-section standards. International Atomic Energy Agency; 2007. STI/PUB/1291.

[2] Carlson AD, Pronyaev VG, Smith DL, et al. International evaluation of neutron cross section standards. Nucl Data Sheets. 2009;110:3215–3324. doi:10.1016/j.nds.2009.11.001.

[3] Carlson AD, Pronyaev VG, Capote R, et al. Evaluation of the neutron data standards. Nucl Data Sheets. 2018;148:143–188. doi:10.1016/j.nds.2018.02.002.

[4] Iwamoto O. Development of a comprehensive code for nuclear data evaluation, CCONe, and validation using neutron-induced cross sections for uranium isotopes. J Nucl Sci Technol. 2007;44:687–697. doi:10.1080/18811248.2007.9711857.

[5] Kawano T. CoH$_3$: the coupled-channels and Hauser-Feshbach code. Springer Proc Phys. 2021;254:28–34. doi:10.1007/978-3-030-58082-7_3.

[6] Koning AJ, Roachman D. Modern nuclear data evaluation with the TALYS code system. Nucl Data Sheets. 2012;113:2841–2934. doi:10.1016/j.nds.2012.11.002.

[7] Herman M, Capote R, Carlson BV et al. EMPIRE: Nuclear reaction model code system for data evaluation. Nucl Data Sheets. 2007;108:2655–2715. doi:10.1016/j.nds.2007.11.003.

[8] Otuka N, Dupont E, Semkova V, et al. Towards a more complete and accurate experimental nuclear reaction data library (EXFOR): International collaboration between Nuclear Reaction Data Centres (NRDC). Nucl Data Sheets. 2014;120:272–276. doi:10.1016/j.nds.2014.07.065.

[9] Iwamoto O, Iwamoto N, Kunieda S, et al. The CCONe code system and its application to nuclear data evaluation for fission and other reactions. Nucl Data Sheets. 2016;131:259–288. doi:10.1016/j.nds.2015.12.004.

[10] Sowerby MG, Patrick BH. A simultaneous evaluation of the fission cross-sections of $^{235}$U, $^{239}$Pu and $^{238}$U and the capture cross-section of $^{238}$U in the energy range 100 eV to 20 MeV. In: Proceedings of the Second International Conference on Nuclear Data for Reactors, Helsinki, 15–19 June 1970, Vol. 2; International Atomic Energy Agency; p. 703–716. STI/PUB/259.

[11] Sowerby MG, Patrick BH, Mather DS. A simultaneous evaluation of the fission cross-sections of U-235, Pu-239 and U-238 and the capture cross-section of U-238 in the energy range 100 eV to 20 MeV. Ann Nucl Sci Eng. 1974;1:409–435. doi:10.1016/0302-9277(74)90066-X.

[12] Poenitz WP. Interpretation and intercomparison of standard cross sections. In: Proceedings of the Symposium on Neutron Standards and Flux Normalization, Argonne, 21–23 October 1970; 1971. p. 331–340; AEC Symposium Series 23, CONF-701002.

[13] Matsunobu H, Kanda Y, Kawai M, et al. Simultaneous evaluation of the nuclear data for heavy nuclides. In: Proceedings of the 1978 Seminar on Nuclear Data, Tokai, 20–21 December 1978; Japan Atomic Energy Research Institute; 1979. p. 209–242. doi:10.11484/jaeri-m-8163 JAERI-M 8163. In Japanese.

[14] Matsunobu H, Kanda Y, Kawai M, et al. Simultaneous evaluation of the nuclear data for heavy nuclides. In: Proceedings of the International Conference on Nuclear Cross Sections for Technology, Knoxville, 22–26 October 1979; 1980. p. 715–719; NBS Special Publication 594.

[15] Uenohora Y, Kanda Y. Simultaneous evaluation of neutron cross section and their covariances for some reaction of heavy nuclei. In: Proceedings of the International Conference on Nuclear Data for Science and Technology, Antwerp, 6–10 September 1982. Central Bureau for Nuclear Measurements; 1983. p. 639–642. doi:10.1007/978-94-009-7099-1_138; EUR 8355.

[16] Uenohora Y, Kanda Y. Significance of covariance matrices in nuclear data evaluation. J Nucl Sci Technol. 1983;20:967–969. doi:10.1080/18811248.1983.9733495.

[17] Kikuchi K. Japanese Evaluated Nuclear Data Library, Version-3 — JENDL-3 —. In: Proceedings of the International Conference on Nuclear Data for Science and Technology, Jülich, 13–17 May 1991; 1992. p. 793–799. doi:10.1007/978-3-642-58113-7_223.

[18] Kanda Y, Uenohora Y, Murata T, et al. Simultaneous evaluation of fission and capture cross sections and their covariances for heavy nuclei. Rad Eff. 1986;96:225–229. doi:10.1080/00337578608211740.

[19] Shibata K, Nakagawa T, Asami T, et al. Japanese Evaluated Nuclear Data Library, Version-3 — JENDL-3 —. Japan Atomic Energy Research Institute; 1990. JAERI 1319. doi:10.11484/jaeri-1319.

[20] Nakagawa T, Shibata K, Chiba S, et al. Japanese Evaluated Nuclear Data Library Version 3 Revision-2: JENDL-3.2. J Nucl Sci Technol. 1995;32:1259–1271. doi:10.1080/18811248.1995.9731849.

[21] Shibata K, Kawano T, Nakagawa T, et al. Japanese Evaluated Nuclear Data Library Version 3 Revision-3: JENDL-3.3. J Nucl Sci Technol. 2002;39:1125–1136. doi:10.1080/18811248.2002.9715303.
[22] Kawano T, Matsunobu H, Murata T, et al. Simultaneous evaluation of fission cross sections of uranium and plutonium isotopes for JENDL-3.3. J Nucl Sci Technol. 2000;37:327–334. doi:10.1080/18811248.2000.9714902.

[23] Kawano T, Matsunobu H, Murata T, et al. Evaluation of fission cross sections and covariances for 235U, 236U, 237U, 238U, 239Pu, 240Pu, and 241Pu. Japan Atomic Energy Research Institute; 2000. JAERI-Research 2000–004. doi:10.11484/jaeri-research-2000-004.

[24] Iwamoto O, Nakagawa T, Otuka N, et al. JENDL Actinide File 2008. J Nucl Sci Technol. 2009;46:510–528. doi:10.1080/18811248.2007.9711557.

[25] Shibata K, Iwamoto O, Nakagawa T, et al. JENDL-4.0: A new library for nuclear science and engineering. J Nucl Sci Technol. 2011;48:1–30. doi:10.1080/18811248.2011.9711675.

[26] Poenitz WP, Aumeier SE. The simultaneous evaluation of the standards and other cross sections of importance for technology. Argonne National Laboratory; 1997. ANL/NDM-139.

[27] Otuka N, Capote R, Kopecky S, et al. Experimental uncertainty and covariance information in EXFOR library. EPJ Web Conf. 2012;27:00007. doi:10.1051/epjconf/20122700007.

[28] Smith DL, Otuka N. Experimental nuclear reaction data uncertainties: Basic concepts and documentation. Nucl Data Sheets. 2012;113:3006–3053. doi:10.1016/j.nds.2012.11.004.

[29] Zerkin V. Extension of EXFOR formats manual; 2013. Working Paper WP2013-35 distributed in the Technical Meeting on International Network of Nuclear Reaction Data Centres. Vienna, Austria, 23–25 April 2013.

[30] Otuka N, Smith DL. Documentation of uncertainties in experimental cross sections for EXFOR. Nucl Data Sheets. 2014;120:281–284. doi:10.1016/j.nds.2014.07.067.

[31] Dupont E, Otuka N, Cabellos O, et al. Dissemination of data measured at the CERN n_TOF facility. EPJ Web Conf. 2017;146:07002. doi:10.1051/epjconf/201714607002.

[32] Trkov A, Griffin PJ, Simakov SP, et al. IRDF-II: A new neutron metrology library. Nucl Data Sheets. 2020;163:1–108. doi:10.1016/j.nds.2019.12.001.

[33] Iwamoto O, Iwamoto N, Shibata K, et al. Status of JENDL. EPJ Web Conf. 2020;239:09002. doi:10.1051/epjconf/202023909002.

[34] Blokhin AL, Gai EV, Ignatyuk AV, et al. New version of neutron data library BROND-3.1. Voprosy Atomnoy Nauki i Tekhniki, Seriya Yaderno-Reaktorny Konstanty. 2016(2):62–93. In Russian.

[35] Ge Z, Xu R, Wu H, et al. CENDL-3.2: The new version of Chinese general purpose evaluated nuclear data library. EPJ Web Conf. 2020;239:09001. doi:10.1051/epjconf/202023909001.

[36] Brown DA, Chadwick MB, Capote R, et al. ENDF/ B-VIII.0: The 8th major release of the nuclear reaction data library with CIELO-project cross sections, new standards and thermal scattering data. Nucl Data Sheets. 2018;148:1–142. doi:10.1016/j.nds.2018.02.001.

[37] Plompen AJ, Cabellos O, De Saint Jean C, et al. The joint evaluated fission and fusion nuclear data library, JEFF-3.3. Eur Phys J A. 2020;56:181. doi:10.1140/epja/s10050-020-00141-9.

[38] Tang G, Bao S, Cao W, et al. Evaluation of neutron nuclear data of 239U. Comm Nucl Data Progress. 1991;6:279–287. Also available as INDC(CPR)-025.

[39] Cai D, Yu B, Wang Z, et al. Evaluation of neutron nuclear data for 239Pu. Comm Nucl Data Progress Suppl. 1992;6:84–97. Also available as INDC(CPR)-028.

[40] Liang Q, Yan S, Shen Q, et al. Evaluation of neutron nuclear data of 239Pu for CENDL-2. Comm Nucl Data Progress Suppl. 1992;6:72–84. Also available as INDC(CPR)-028.

[41] Carlson AD, Poenitz WP, Hale GM, et al. The ENDF/ B-VI neutron cross section measurement standards. National Institute of Standards and Technology. 1993. NISTIR 5177.

[42] Westcott CH, Ekberg K, Hanna GC, et al. A survey of values of the 2200 m/s constants for four fissile nuclides. Atomic Energy Rev. 1965;3(2):3–60.

[43] Hanna GC, Westcott CH, Lemml HD, et al. Revision of values for the 2200 m/s constants for four fissile nuclides. Atomic Energy Rev. 1969;7(4):3–92.

[44] Lemml HD. The third IAEA evaluation of the 2200 m/s and 20°C Maxwellian neutron data for U-233, U-235, Pu-239 and Pu-241. In: Proceedings of the Conference on Nuclear Cross Sections and Technology, Washington, D.C., 3–7 March 1975; Vol. 1; p. 286–292; NBS Special Publication 425.

[45] Lemml HD, Axton EJ, Deruyttjer AJ, et al. The third IAEA review of the 2200 m/s and 20°C Maxwellian neutron data for U-233, U-235, Pu-239, Pu-241 and the spontaneous neutron yield of Cf-252. International Atomic Energy Agency; 1975. INDC(NDS)-132.

[46] Poenitz WP. Data interpretation, objective evaluation procedures and mathematical techniques for the evaluation of energy-dependent ratio, shape and cross section data. In: Proceedings of the Conference on Nuclear Data Evaluation Methods and Procedures, Upton, NY, 22–25 September 1980. International Atomic Energy Agency; 1981. p. 249–289; INDC(USA)-85.

[47] Calviani M, Praena J, Abbondanno U, et al. High-accuracy 239(n, f) cross-section measurement at the white-neutron source n_TOF from near-thermal to 1 MeV neutron energy. Phys Rev C. 2009;80:044604. doi:10.1103/PhysRevC.80.044604. EXFOR 23072.

[48] Tovesson F, Birgersson E, Flenius M, et al. 235Pu(n,f) cross section up to E<sub>n</sub>=8.5 MeV. Nucl Phys A. 2004;733:3–19. doi:10.1016/j.nuclphysa.2003.11.054. EXFOR 22698.

[49] Guber KH, Spencer RR, Leal LC, et al. New high-resolution fission cross-section measurements of 235U in the 0.4-eV to 700-keV energy range. Nucl Sci Eng. 2000;135:141–149. doi:10.13182/NSE00-A2130. EXFOR 13890.

[50] Shpakov VI. Absolute measurements of the fission cross-sections for important nuclides. International Atomic Energy Agency; 1989. INDC(CCP)-302. p. 33–40. EXFOR 40927.

[51] Zasadny KR, Agrawal HM, Mahdavi M, et al. Measurement of the 14-MeV fission cross sections for 235U and 237Np. Trans Am Nucl Soc. 1984;47:425–427. EXFOR 12910.

[52] Dushman VN, Fomichev AV, Kovalenko SS, et al. Statistical analysis of experimental data on the cross sections of 233,235,238U, 237Np, 239,242Pu fission by
neutrons of energy 2.6, 8.5, and 14.5 MeV. Soviet Atomic Energy. 1983;55:656–660. doi:10.1007/BF01124127. EXFOR 51001.

[53] Murzin AV, Rudyk AF, Libman VA. Measurement of the $^{233}$U and $^{235}$U fission cross sections at neutron energy of 24.5 keV. In: Proceedings of the 5th All Union Conference on Neutron Physics, Kyiv, 15–19 September 1980; Vol. 2; 1980. p. 257–261. In Russian. EXFOR 40587.

[54] Zhagrov EA, Nemilov YuA, Platonov AV, et al. Fission cross sections of $^{233}$U and $^{235}$U in intermediate neutron energy range. In: Proceedings of the 5th All Union Conference on Neutron Physics, Kyiv, 15–19 September 1980; Vol. 3; 1980. p. 45–48. In Russian. EXFOR 40610.

[55] Poenitz WP. Absolute measurements of the $^{233}$U (n,f) cross section between 0.13 and 8 MeV. Argonne National Laboratory, 1978;ANL/NDDM-36. EXFOR 10756.

[56] Gwinn R, Silver EG, Ingle RW, et al. Measurement of the neutron capture and fission cross sections of $^{239}$Pu and $^{235}$U, 0.02 eV to 200 keV, the neutron capture cross sections of $^{197}$Au, 10 to 30 keV, and neutron fission cross sections of $^{233}$U, 5 to 200 keV. Nucl Sci Eng. 1976;59:79–105. doi:10.13182/NSE76-A15682. EXFOR 10267.

[57] Yan W, Ye Z, Yuan H, et al. Measurement of $^{233}$U fission cross section in fast neutron energy region. At Energy Sci Technol. 1975;9:133–142. In Chinese. EXFOR 32625.

[58] Blons J, Derrien H, Michaudon A. Measurement and analysis of the fission cross section of $^{233}$U and $^{235}$U for neutron energies below 30 keV. In: Proceedings of the Third Conference on Neutron Cross Sections and Technology, Knoxville, 15–17 March 1971; Vol. 2; 1971. p. 829–835. EXFOR 20446,51008.

[59] Tovesson F, Laptev A, Hill TS. Fast neutron–induced fission cross sections of $^{233,234,235}$U up to 200 MeV. Nucl Sci Eng. 2014;178:57–65. doi:10.13182/NSE13-56. EXFOR 14402.

[60] Belloni F, Calviani M, Colonna N, et al. Neutron-induced fission cross-section of $^{233}$U in the energy range 0.5 < $E_n$ < 20 MeV. Eur Phys J A. 2011;47:2. doi:10.1140/epja/i2011-11002-y. EXFOR 23128.

[61] Shcherbakov O, Donets A, Evdokimov A, et al. Neutron-induced fission of $^{233}$U, $^{238}$U, $^{232}$Th, $^{235}$Pu, $^{235}$Np, $^{209}$Bi and $^{209}$Po relative to $^{235}$U in the energy range 1–200 MeV. J Nucl Sci Tech Suppl. 2002;2:230–233. doi:10.1080/00222313.2002.10875081. EXFOR 41455.

[62] Shapak DL. Angular anisotropy of fragments from $^{235}$U fission induced by 0.02–6.38 MeV neutrons. Phys At Nuclei. 1998;61:1333–1339. EXFOR 41432.

[63] Meadows JW. The fission cross sections of $^{230}$Th, $^{231}$Th, $^{232}$U, $^{233}$U, $^{234}$U, $^{235}$U, $^{235}$Np, $^{238}$Pu and $^{240}$Pu relative to $^{235}$U at 14.74 MeV neutron energy. Ann Nucl Energy. 1988;15:421–429. doi:10.1016/0306-4599(88)90038-2. EXFOR 13134.

[64] Manabe F, Kanda K, Iwasaki T, et al. Measurements of neutron induced fission cross section ratios of $^{230}$Th, $^{231}$Th, $^{232}$U, $^{233}$U, $^{234}$U, $^{235}$U, $^{238}$U, $^{238}$Np, $^{242}$Pu and $^{243}$Am relative to $^{235}$U around 14 MeV. Tech Rep Tohoku Univ. 1988;52:97–126. EXFOR 22282.

[65] Kanda K, Imaaruoka H, Yoshida K, et al. Measurement of fast neutron induced fission cross sections of $^{232}$Th, $^{233}$U and $^{234}$U relative to $^{235}$U. Rad Eff. 1986;93:233–236. doi:10.1080/003375786080207460. EXFOR 22014.

[66] Carlson GW, Behrens JW. Measurement of the fission cross sections of uranium-233 and plutonium-239 relative to uranium-235 from 1 keV to 30 MeV. Nucl Sci Eng. 1978;66:205–216. doi:10.13182/NSE78-1. EXFOR 10562.

[67] Fursov BI, Kupriyanov VM, Smirenkii GN. Measurement of the $^{233}$U and $^{241}$Pu fission cross sections relative to the $^{235}$U fission cross section in the neutron energy range 0.024–7.4 MeV. Soviet Atomic Energy. 1978;44:262–265. doi:10.1016/BF01117632. EXFOR 40474.

[68] Meadows JW. The ratio of the uranium-233 to uranium-235 fission cross section. Nucl Sci Eng. 1974;54:317–321. doi:10.13182/NSE74-1. EXFOR 10236.

[69] Pfletschinger E, Käppeler F. A measurement of the fission cross sections of $^{239}$Pu and $^{235}$U relative to $^{235}$U. Nucl Sci Eng. 1970;40:375–382. doi:10.13182/NSE70-A20188. EXFOR 20363.

[70] Amaducci S, Cosentino L, Barbagallo M, et al. Measurement of the $^{235}$U(n,f) cross section relative to the $^6$Li(n,t) and $^{10}$B(n,α) standards from thermal to 170 keV neutron energy range at $n$ TOF. Eur Phys J A. 2019;55:120. doi:10.1140/epja/i2019-12802-7. EXFOR 23453,51006.

[71] Noilte R, Allie MS, Brooks FD, et al. Cross sections for neutron-induced fission of $^{235}$U, $^{238}$U, $^{209}$Bi, and $^{208}$Po in the energy range from 33 to 200 MeV measured relative to n-p scattering. Nucl Sci Eng. 2007;156:197–210. doi:10.13182/NSE06-14. EXFOR 23078.

[72] Carlson AD, Wasson OA, Lisowski PW, et al. Measurements of the $^{235}$U(n,f) cross section in the 3 to 30 neutron energy region. In: Proceedings of the International Conference on Nuclear Data for Science and Technology, Jülich, 13–17 May 1991; 1992. p. 518–520. doi:10.1007/978-3-642-58113-7_147. EXFOR 14015.

[73] Lisowski PW, Gavron A, Parker WE, et al. Fission cross sections in the intermediate energy region. In: Proceedings of a Specialists’ Meeting on Neutron Cross Section Standards for the Energy Region above 20 MeV, Uppsala, 21–23 May 1991; 1991. p. 177–186. NEANDC-305. EXFOR 14016.

[74] Merla K, H ausch P, Herbach CM, et al. Absolute measurements of neutron induced fission cross-sections of $^{235}$U, $^{238}$U, $^{239}$Np and $^{239}$Pu using the time correlated associated particle method (TCAPM). In: Proceedings of the International Conference on Nuclear Data for Science and Technology, Jülich, 13–17 May 1991; 1992. p. 510–513. doi:10.1007/978-3-642-58113-7_145. EXFOR 22304,51010.

[75] Kalinin VA, Kuz’min VN, Solin LM, et al. Correction to the results of absolute measurements of the $^{235}$U fission cross section with 1.9 and 2.4-MeV neutrons. Soviet Atomic Energy. 1991;71:700–704. doi:10.1007/BF01121671. EXFOR 41112.

[76] Iwasaki T, Karino Y, Matsuyma S, et al. Measurement of $^{235}$U fission cross section around 14 MeV. In: Proceedings of the International Conference on Nuclear Data for Science and Technology, Mito, 30 May–3 June 1988; 1988. p. 87–90. EXFOR 22091.
[77] Li J, Shen G, Ye Z, et al. Absolute measurement of $^{235}$U fission cross section induced by 14.2 MeV neutrons. Chin J Nucl Phys. 1988;10:237–243. In Chinese. EXFOR 30721.

[78] Carlson AD, Behrens JW, Johnson RG, et al. Absolute measurements of the $^{235}$U(n,f) cross-section for neutron energies from 0.3 to 3 MeV. In: Proceedings of an Advisory Group Meeting on Nuclear Standard Reference Data, Geel, 12–16 November 1984. International Atomic Energy Agency; 1985. p. 162–166; IAEA-TECDOC-335. EXFOR 10987.

[79] Dias MS, Carlson AD, Johnson RG, et al. Application of the dual thin scintillator neutron flux monitor in a $^{235}$U(n,f) cross-section measurement. In: Proceedings of an Advisory Group Meeting on Nuclear Standard Reference Data, Geel, 12–16 November 1984. International Atomic Energy Agency; 1985. p. 467–470; IAEA-TECDOC-335. EXFOR 12924.

[80] Weston LW, Todd JH. Subthreshold fission cross section of $^{240}$Pu and the fission cross sections of $^{235}$U and $^{239}$Pu. Nucl Sci Eng. 1984;88:567–578. doi:10.13182/NSE84-A18373. EXFOR 12877.

[81] Li J, Li A, Rong C, et al. Absolute measurements of fission cross sections for $^{235}$U and $^{239}$Pu induced by 14.7 MeV neutron using the associated particle method. Chin J Nucl Phys. 1983;5:45–50. In Chinese. EXFOR 30634.

[82] Wasson OA, Meier MM, Duvall KC. Absolute measurement of the uranium-235 fission cross section from 0.2 to 1.2 MeV. Nucl Sci Eng. 1982;81:196–212. doi:10.13182/NSE82-A20085. EXFOR 10950.

[83] Wasson OA, Carlson AD, Duvall KC. Measurement of the $^{235}$U neutron-induced fission cross section at 14.1 MeV. Nucl Sci Eng. 1982;80:282–303. doi:10.13182/NSE82-A21431. EXFOR 10971.

[84] Mahdavi M, Knoll GF, Robertson JC. Measurements of the 14 MeV fission cross-sections for $^{235}$U and $^{239}$Pu. In: Proceedings of the International Conference on Nuclear Data for Science and Technology, Antwerp, 6–10 September 1982. Central Bureau for Nuclear Measurements; 1983. p. 58–61. doi:10.1007/978-94-009-7099-1_12; EUR 8355. EXFOR 12826.

[85] Cancé M, Grenier G. Mesures absolues des sections efficaces de fission de $^{235}$U à 2.5 MeV et 4.5 MeV et de $^{241}$Am à 14.6 MeV. Centre d’Études de Bruyères-Châtel; 1981; CEA-N-2194. In French. EXFOR 21620.

[86] Arlt R, Josch M, Musiol G, et al. Absolute fission cross section measurement on $^{235}$U at 8.4 MeV neutron energy. In: Proceedings of the X-th International Symposium on Selected Topics of the Interaction of Fast Neutrons and Heavy Ions with Atomic Nuclei, Gausig, 17–21 November 1980. International Atomic Energy Agency; 1981. p. 35–39; INDC(GDR)-19. EXFOR 31833.

[87] Salvador-Castineira P, Habensch P, Gökük A, et al. Absolute and relative cross section measurements of $^{235}$NP(n,f) and $^{239}$U(n,f) at the National Physical Laboratory. EPJ Web Conf. 2017;146:04050. doi:10.1051/epjconf/201714604050. EXFOR 23736.

[88] Miller ZW. A measurement of the prompt fission neutron energy spectrum for $^{235}$U(n,f) and the neutron-induced fission cross section for $^{238}$U(n,f) [dissertation]. Dissertation submitted to University of Kentucky; 2015. EXFOR 14529.

[89] Meadows JW, Smith DL, Greenwood LR, et al. Measurement of fast-neutron activation cross sections for copper, europium, hafnium, iron, nickel, silver, terbium and titanium at 10.0 and 14.7 MeV and for the Be(d,p) thick-target spectrum. Ann Nucl Energy. 1996;23:877–899. doi:10.1016/0306-4549(95)00068-2. EXFOR 13586.

[90] Eismont VP, Prokofyev AV, Smirnov AN, et al. Relative and absolute neutron-induced fission cross sections of $^{208}$Pb, $^{209}$Bi, and $^{238}$U in the intermediate energy region. Phys Rev C. 1996;53:2911–2918. doi:10.1103/PhysRevC.53.2911. EXFOR 22321.

[91] Meadows JW, Smith DL, Geraldo IP. A search for possible structure in the $^{238}$U(n,f) cross section near 2.3 MeV. Ann Nucl Energy. 1989;16:471–476. doi:10.1016/0306-4549(89)90061-3. EXFOR 13169.

[92] Wu J, Deng X, Rong C, et al. Measurement of fission cross section for $^{235}$U induced by fast neutron. Chin J Nucl Phys. 1983;5:158–165. In Chinese. EXFOR 30669.

[93] Hu Z, Qi B, Li A, et al. Measurement of neutron-induced fission cross section of $^{235}$U at 14 MeV. At Energy Sci Technol. 1980;14:201–203. In Chinese. EXFOR 32766.

[94] Alkhazov ID, Dushin VN, Kovalenko SS, et al. Fission cross sections of $^{235}$U and $^{238}$U to neutrons with an energy of 14.7 MeV. Soviet Atomic Energy. 1979;47:1040–1043. doi:10.1007/BF01126187. EXFOR 31832.

[95] Cancé M, Grenier G. Absolute neutron fission cross sections of $^{235}$U, $^{239}$U, and $^{238}$Pu at 13.9 and 14.6 MeV. Nucl Sci Eng. 1978;68:197–203. doi:10.13182/NSE78-A27290. EXFOR 20779.

[96] Vorotnikov PE, Dubrovin SM, Otroschchenko GA, et al. Sub-threshold cross-section for $^{238}$U fission by neutrons. International Atomic Energy Agency; 1976. INDC(CCP)-66. p. 6–7. EXFOR 40483.

[97] Behrens JW, Carlson GW. Measurements of neutron-induced fission cross-section ratios involving isotopes of uranium and plutonium. In: Proceedings of the NEANCD/NEACRP Specialists Meeting on Fast Neutron Fission Cross Sections of U-233, U-235, U-238, and Pu-239, Argonne, 28–30 June 1976; 1976. p. 47–69; ANL-76-90, NEANCD(US)-199. EXFOR 10422.

[98] Wen J, Yang Y, Wen Z, et al. Measurement of the U-238/U-235 fission cross section ratio at CSNS – Back-n WNS. Ann Nucl Energy. 2020;140:107301. doi:10.1016/j.anucene.2019.107301. EXFOR 32798.

[99] Casperson RJ, Asnér DM, Baker J, et al. Measurement of the normalized $^{238}$U(n,f)/$^{235}$U(n,f) cross section ratio from threshold to 30 MeV with the NIFTFE fission Time Projection Chamber. Phys Rev C. 2018;97:034618. doi:10.1103/PhysRevC.97.034618. EXFOR 14498.

[100] Paradela C, Calviani M, Tarrio D, et al. High-accuracy determination of the $^{235}$U/$^{238}$U fission cross section ratio up to 1 GeV at n_TOF at CERN. Phys Rev C. 2015;91:024602. doi:10.1103/PhysRevC.91.024602. EXFOR 23269,51005.

[101] Li J, Liu W, Zhou S, et al. The ratio of the $^{238}$U to $^{235}$U fission cross section at 14.7 MeV. Chin J Nucl Phys. 1989;11(3):17–24. EXFOR 30722.

[102] Kanda K, Sato O, Yoshida K, et al. Measurements of fast neutron-induced fission cross sections. In: Proceedings of the 1983 Seminar on Nuclear Data, Tokai, 13–15 November 1984. Japan Atomic Energy
[103] García I, Miron C, Dobrea D, et al. Measuring of the integral cross sections at 14 MeV, for reactions $^{115}$In(n, n'), $^{197}$Au(n,2n), $^{209}$Nb(n,2n), $^{27}$Al(n,n), $^{56}$Fe(n,p), $^{239}$Pu (n, f), $^{238}$U(n,f), $^{232}$Th(n,f) and $^{237}$Np(n,f). Revue Roumaine de Physique. 1984;29:421–426. EXFOR 40831.

[104] Goverdovskii AA, Kuz'minov BD, Mitrofanov VF, et al. Measurement of the ratio of the fission cross sections of $^{238}$U and $^{235}$U for neutron energies in the range 5.4–10.4 MeV. Soviet Atomic Energy. 1984;56:173–176. doi:10.1007/BF01131462. EXFOR 40831.

[105] Várnagy M, Csikai J. A new approach to measuring fission cross-section ratios. Nucl Instrum Methods Phys Res. 1982;196:465–468. doi:10.1016/0022-1642(82)90115-X. EXFOR 30588.

[106] DiFilippo FC, Perez RB, de Saussure G, et al. Measurement of the uranium-238 to uranium-235 fission cross-section ratio for neutron energies between 0.1 and 25 MeV. Nucl Sci Eng. 1978;68:43–54. doi:10.13182/NSE78-A2769. EXFOR 10653.

[107] Behrens JW, Carlson GW. Measurements of the neutron-induced fission cross sections of $^{234}$U, $^{235}$U, and $^{238}$U relative to $^{235}$U from 0.1 to 30 MeV. Nucl Sci Eng. 1977;63:250–267. doi:10.13182/NSE77-2. EXFOR 10653.

[108] Fursov BI, Kupriyanov VM, Maslennikov BK, et al. Measurement of the ratio of the $^{235}$U and $^{238}$U fission cross sections for fission by 1–7 MeV neutrons. Soviet Atomic Energy. 1977;43:808–813. doi:10.1007/BF01190411. EXFOR 40506.

[109] Cierjacks S, Leugers B, Kari K, et al. Measurements of neutron induced fission cross section ratios at the Karlsruhe isochronous cyclotron. In: Proceedings of the NEANDC/NEACRP Specialists Meeting on Fast Neutron Fission Cross Sections of U-233, U-235, U-238, and Pu-239, Argonne, 28–30 June 1976. p. 94–113; ANL-76-90,NEANDC(US)-199. EXFOR 20409.

[110] Nordborg C, Conde H, Strömberg LG. Fission cross section ratio measurement of $^{239}$U to $^{235}$U for neutrons with energies between 4.7 and 8.9 MeV. In: Proceedings of the NEANDC/NEACRP Specialists Meeting on Fast Neutron Fission Cross Sections of U-233, U-235, U-238, and Pu-239, Argonne, 28–30 June 1976; 1976. p. 128–140; ANL-76-90, NEANDC(US)-199. EXFOR 20869.

[111] Cance M, Grenier G. Measurements of $^{238}$U/$^{235}$U fission cross section ratios in the energy range 2–7 MeV. In: Proceedings of the NEANDC/NEACRP Specialists Meeting on Fast Neutron Fission Cross Sections of U-233, U-235, U-238, and Pu-239, Argonne, 28–30 June 1976; 1976. p. 141–148; ANL-76-90, NEANDC(US)-199. EXFOR 20870.

[112] Meadows JW. The ratio of the uranium-238 to uranium-235 fission cross sections from 5.3 to 10.3 MeV. Nucl Sci Eng. 1975;58:255–257. doi:10.13182/NSE75-A28229. EXFOR 10506.

[113] Poenitz WP, Armanzi RJ. Measurements of the fission cross section ratio of $^{238}$U to $^{235}$U from 2–3 MeV. J Nucl Energy. 1972;26:483–487. doi:10.1016/0022-3107(72)90032-9. EXFOR 10232,51002.

[114] Meadows JW. The ratio of the uranium-238 to uranium-235 fission cross sections from 1 to 5 MeV. Nucl Sci Eng. 1972;49:310–316. doi:10.13182/NSE72-A22544. EXFOR 10237.

[115] Weston LW, Todd JH. High-resolution fission cross-section measurements of $^{238}$U and $^{239}$Pu. Nucl Sci Eng. 1992;111:415–421. doi:10.13182/NSE92-A15488. EXFOR 13488.

[116] Zhou X, Yan W, Zhou H, et al. Fast neutron induced fission cross section for Pu-239. In: Proceedings of the International Conference on Nuclear Data for Science and Technology, Antwerp, 6–10 September 1982. Central Bureau for Nuclear Measurements; 1983. p. 36–38. doi:10.1007/978-94-009-7099-1_7. EUR 8355. EXFOR 30670.

[117] Ryabov YuV. Measurements of the fission cross section of $^{239}$Pu by neutrons with energy from 10 eV to 100 keV. Soviet Atomic Energy. 1979;46:178–182. doi:10.1007/BF01125732. EXFOR 40487.

[118] Davis MC, Knoll GF, Robertson JC, et al. Absolute measurements of $^{235}$U and $^{239}$Pu fission cross-sections with photon neutrons. Ann Nucl Energy. 1978;5:569–581. doi:10.1016/0306-4549(78)90031-2. EXFOR 10314.

[119] Szabo I, Marquette JP. Measurement of the neutron induced fission cross sections of uranium 235 and plutonium 239 in the MeV energy range. In: Proceedings of the NEANDC/NEACRP Specialists Meeting on Fast Neutron Fission Cross Sections of U-233, U-235, U-238, and Pu-239, Argonne, 28–30 June 1976; 1976. p. 208–224; ANL-76-90, NEANDC(US)-199. EXFOR 20618.

[120] Blons J, Derrien H, Michaudon A. Mesure a haute resolution et analyse de la section efficace de fission du plutonium-239. In: Proceedings of the Second International Conference on Nuclear Data for Reactors, Helsinki, 15–19 June 1970; Vol. 1. International Atomic Energy Agency; 1980. p. 513–524. In French. STI/PUB/259. EXFOR 20001,51007.

[121] Szabo I, Leroy JL, Marquette JP. Mesure absolue de la section efficace de fission de $^{235}$U, de $^{239}$Pu et de $^{241}$Pu entre 10 keV et 2.6 MeV. In: Proceedings of the 2nd National Soviet Conference on Neutron Physics, Kyiv, 28 1 May–June 1973; Vol. 3; 1974. p. 27–45. In French. EXFOR 20570.

[122] Schomberg MG, Sowerby MG, Boyce DA, et al. Ratio of the capture and fission cross-sections of $^{239}$Pu in the energy range 100 eV to 30 keV. In: Proceedings of the Second International Conference on Nuclear Data for Reactors, Helsinki, 15–19 June 1970; Vol. 1. International Atomic Energy Agency; 1970. p. 315–330. STI/PUB/259. EXFOR 20476.

[123] Szabo I, Filippi G, Huet JL, et al. New absolute measurement of the neutron-induced fission cross sections of $^{235}$U, $^{239}$Pu, and $^{241}$Pu from 17 keV to 1 MeV. In: Proceedings of the Symposium on Neutron Standards and Flux Normalization, Argonne, 21–23 October 1970; 1971. p. 257–271; CONF-700102. EXFOR 20567.

[124] Tovesson F, Hill TS. Cross sections for $^{238}$Pu(n,f) and $^{241}$Pu(n,f) in the range $E_n = 0.01$ eV to 200 MeV. Nucl Sci Eng. 2010;165:224–231. doi:10.13182/NSE09-41. EXFOR 14271.
[125] Staples P, Morley K. Neutron-induced fission cross-section ratios for $^{239}$Pu, $^{240}$Pu, $^{242}$Pu, and $^{244}$Pu relative to $^{235}$U from 0.5 to 400 MeV. Nucl Sci Eng. 1998;129:149–163. doi:10.13182/NSE98-A1969. EXFOR 13801.

[126] Weston LW, Todd JH. Neutron fission cross sections of $^{239}$Pu and $^{244}$Pu relative to $^{235}$U. Nucl Sci Eng. 1983;84:248–259. doi:10.13182/NSE83-A17793. EXFOR 12766.

[127] Meadows JW. The fission cross sections of plutonium-239 and plutonium-242 relative to uranium-235 from 0.1 to 10 MeV. Nucl Sci Eng. 1978;68:360–363. doi:10.13182/NSE78-A27315. EXFOR 10734.

[128] Kari K. Messung der Spaltqerschnitte von $^{239}$Pu und $^{240}$Pu relativ zum Spaltquerschnitt von $^{235}$U und Streuquerschnitt N(p,n) in dem Neutronenenergiebereich zwischen 0.5 - 20 MeV, Kernforschungszentrum Karlsruhe, 1978;KfK 2673. In German. EXFOR 20786.

[129] Fursov BI, Kupriyanov VM, Ivanov VI, et al. Measurement of the ratio of the $^{239}$Pu and $^{235}$U fission cross sections for 0.024–7.4-MeV neutrons. Soviet Atomic Energy. 1977;43:894–899. EXFOR 40824. doi:10.1103/PhysRevC.90.011303.

[130] Gayther DB. Measurement of the $^{239}$Pu fission cross-section and its ratio to the $^{235}$U fission cross-section in the energy range from 1 keV to 1 MeV. In: Proceedings of the Conference on Nuclear Cross Sections and Technology, Washington, D.C., 3–7 March 1975; Vol. 2; 1975: p. 564–567. EXFOR 20428.

[131] Poenitz WP. Additional measurements of the ratio of the fission cross sections of plutonium-239 and uranium-235, Nucl Sci Eng. 1972;47:228–230. doi:10.13182/NSE72-A22401. EXFOR 10253.

[132] Szabo I, Filippi G, Huet J, et al. $^{235}$U fission cross section from 10 keV to 200 keV. In: Proceedings of the Third Conference on Neutron Cross Sections and Technology, Knoxville, 15–17 March 1971; Vol. 2; 1971: p. 573–583. EXFOR 20569.

[133] Poenitz WP. Measurement of the ratios of capture and fission neutron cross sections of $^{235}$U, $^{238}$U, and $^{239}$U at 130 to 1400 keV. Nucl Sci Eng. 1970;40:383–388. doi:10.13182/NSE70-A20189. EXFOR 10086.

[134] Salvador-Castiñeira P, Bryš T, Eykens R, et al. Neutron-induced fission cross section of $^{240}$Pu from 0.5 MeV to 3 MeV. Phys Rev C. 2015;92:014620. doi:10.1103/PhysRevC.92.014620. EXFOR 23281.

[135] Gul K, Ahmad M, Anwar M, et al. Measurements of neutron fission cross sections of $^{237}$Np, $^{240}$Pu, $^{241}$Pu, $^{242}$Pu, and $^{243}$Am at 14.7 MeV. Nucl Sci Eng. 1986;94:42–45. doi:10.13182/NSE86-A17115. EXFOR 31711.

[136] Aleksandrov BM, Solovjev SM, Soloshenko PS, et al. Neutron fission cross-sections for $^{241}$Am, $^{238}$, $^{240}$, and $^{241}$Pu. International Atomic Energy Agency; 1983. INDC(CCP)-213. p. 3–4. In Russian. EXFOR 40673.

[137] Cancé M, Grenier G. Mesures absolues de $^{240}$Pu(n,f), $^{242}$Pu(n,f), et $^{237}$Np(n,f) à l'énergie incidente de 2,5 MeV. In: Proceedings of the International Conference on Nuclear Data for Science and Technology, Antwerp, 6–10 September 1982. Central Bureau for Nuclear Measurements; 1983. p. 51–54. doi:10.1007/978-94-009-7099-1_10. EUR 8555. In French. EXFOR 21821.

[138] Budtz-Jørgensen C, Knitter HH. Neutron-induced fission cross section of plutonium-240 in the energy range from 10 keV to 10 MeV. Nucl Sci Eng. 1981;79:380–392. doi:10.13182/NSE81-A21389. EXFOR 21764.

[139] Khan NA, Khan HA, Gul K, et al. A new approach to measure reaction parameters in the 14.8 MeV neutron induced fission of $^{240}$Pu and $^{241}$Pu. Nucl Instrum Methods. 1990;173:137–142. doi:10.1016/0029-554X(90)90578-9. EXFOR 30548.

[140] Stamatopoulos A, Tsinganis A, Colonna N, et al. Investigation of the $^{240}$Pu(n,f) reaction at the n_TOF/EAR2 facility in the 9 meV–6 MeV range. Phys Rev C. 2020;102:014616. doi:10.1103/PhysRevC.102.014616. EXFOR 23458.

[141] Laptev AB, Scherbakov OA, Vorobyev AS, et al. Fast neutron-induced fission of some actinides and sub-actinides. In: Proceedings of the International Conference on Fission and Properties of Neutron-Rich Nuclei, Sanibel Island, 10–15 November 1997; 1998. p. 462–468. doi:10.1142/3850. EXFOR 41487.

[142] Iwasaki T, Manabe F, Baba M, et al. Measurement of fast neutron induced fission cross section ratios of Pu-240 and Pu-242 relative to U-235. J Nucl Sci Technol. 1990;27:885–898. doi:10.1080/18811248.1990.9731269. EXFOR 22211.

[143] Behrens JW. Measurement of the subthreshold neutron-induced fission cross section of $^{240}$Pu relative to $^{235}$U from 5 to 300 keV. Nucl Sci Eng. 1983;85:314–318. doi:10.13182/NSE83-A17323. EXFOR 13576.

[144] Meadows JW. The fission cross section of plutonium-240 relative to uranium-235 from 0.35 to 9.6 MeV. Nucl Sci Eng. 1981;79:233–237. doi:10.13182/NSE81-A27412. EXFOR 12714.

[145] Wissak K, Käppeler F. A measurement of the subthreshold neutron fission cross section of plutonium-240 in the energy range from 10 to 250 MeV. Nucl Sci Eng. 1979;69:47–54. doi:10.13182/NSE79-A121284. EXFOR 20766.

[146] Kupriyanov VM, Fursov BI, Maslennikov BK, et al. Measurement of the $^{240}$Pu/$^{238}$U and $^{242}$Pu/$^{238}$U fission cross-section ratios for 0.127–7.4-MeV neutrons. Soviet Atomic Energy. 1979;46:35–39. doi:10.1007/BF01119949. EXFOR 40509.

[147] Behrens JW, Newbury RS, Magana JW. Measurements of the neutron-induced fission cross sections of $^{240}$Pu, $^{242}$Pu, and $^{244}$Pu relative to $^{235}$U from 0.1 to 30 MeV. Nucl Sci Eng. 1978;66:433–441. doi:10.13182/NSE78-A27227. EXFOR 10597.

[148] Frehaut J, Mosinski G, Bois R, et al. Mesure du nombre moyen $\bar{v}_p$ de neutrons prompts emis au cours de la fission induite dans $^{240}$Pu et $^{242}$Pu par des neutrons d'énergie comprise entre 1,5 et 15 MeV. Centre d'Études de Bruyères-Châtel. 1974. CEA-N-4626. In French. EXFOR 20488.

[149] Wagemans C, Deruyter AJ. The $^{241}$Pu(n,f) cross-section and its normalization. In: Proceedings of the International Conference on Nuclear Data for Science and Technology, Antwerp, 6–10 September 1982. Central Bureau for Nuclear Measurements; 1983. p. 69–73. doi:10.1007/978-94-009-7099-1_15 EUR 8355. EXFOR 21811.
[150] Carlson GW, Behrens JW, Cazir JB. A measurement of the fission cross section of plutonium-241 from 8 eV to 70 keV. Nucl Sci Eng. 1977;63:149–152. doi:10.13182/NSE77-A27018. EXFOR 10636.

[151] Blons J, Debril G, Fermandjian J, et al. Mesure et analyse des sections efficaces de fission de l’uranium-235 et du plutonium-241. In: Proceedings of the Second International Conference on Nuclear Data for Reactors, Helsinki, 15–19 June 1970; Vol. 1. International Atomic Energy Agency; 1970. p. 469–480. In French. STI/PUB/259. EXFOR 20484,51009.

[152] Blons J, Derrien H, Michaudon A. Measurement of the fission cross section and analysis of the total and fission cross sections of $^{241}$Pu in the resonance region. In: Proceedings of the Third Conference on Neutron Cross Sections and Technology, Knoxville, 15–17 March 1971; Vol. 2. 1971. p. 836–842. EXFOR 20484,51009.

[153] Käppeler F, Pfetschinger E. A measurement of the fission cross section of plutonium-241 relative to uranium-235. Nucl Sci Eng. 1973;51:124–129. doi:10.13182/NSE73-A26588. EXFOR 20364.

[154] Otuka N, Iwamoto O. EXFOR-based simultaneous evaluation of neutron-induced uranium and plutonium fission cross sections for JENDL-5: Inputs and outputs. International Atomic Energy Agency; 2022. INDC(SEC)-0112.

[155] Leugers B, Cierjacobs S, Brotz P, et al. The $^{235}$U and $^{238}$U neutron induced fission cross sections relative to the H(n,p) cross section. In: Proceedings of the NEANDC/NEACRP Specialists Meeting on Fast Neutron Fission Cross Sections of U-233, U-235, U-238, and Pu-239, Argonne, 28–30 June 1976; 1976. p. 246–257; ANL-76-90,NEANDC(US)-199. EXFOR 20943.

[156] Leugers B. [Private communication with F. Voß]; 2021. EXFOR 20409,20786.

[157] Pronyaev VG. Standards database extension: New results since 1997 (data, which are not included in ANL/NDM-139, 1997). International Atomic Energy Agency; 2003. INDC(NDS)-438. p. 186–198.

[158] CINDA 2006: The comprehensive index of nuclear reaction data: archive 1935-2006. Nuclear Energy Agency, Organisation for Economic Co-operation and Development; 2007.

[159] Alkhazov ID, Drapchinsky LV, Kalinin VA, et al. New results of absolute cross-section measurements for the heavy nuclide fission induced by fast neutrons. In: Proceedings of the International Conference on Nuclear Data for Science and Technology, Mito, 30 May–3 June 1988; 1988. p. 145–148. EXFOR 41013.

[160] Shpak DL, Korolev GG. Measurement of $^{232}$U fission cross section ratio in neutron energy range of 0.060–3.28 MeV. In: Proceedings of the 5th All Union Conference on Neutron Physics, Kyiv, 15–19 September 1980; Vol. 3; 1980. p. 35–39. In Russian. EXFOR 40607.

[161] Schmittroth F, Schenter RE. Finite element basis in data adjustment. Nucl Sci Eng. 1980;74:168–177. doi:10.13182/NSE80-A20116.

[162] Uenohara Y, Kanda Y. The reviews of the simultaneous evaluation and evaluated covariance matrices for the cross sections on heavy nuclides. In: Proceedings of the 1983 Seminar on Nuclear Data, Tokai, 30 November–1 December 1983. Japan Atomic Energy Research Institute; 1984. p. 177–194. doi:10.11484/jaeri-m-84-010. JAERI-M 84-010, INDC(JPN)-84. In Japanese.

[163] Kunieda S, Iwamoto O, Iwamoto N, et al. Overview of JENDL-4.0/HE and benchmark calculations. In: Proceedings of the 2015 Symposium on Nuclear Data, Tokai, 19–20 November, 2015. Japan Atomic Energy Agency; 2016. JAEA-Conf-2016-004. p. 41–46. doi:10.11484/jaea-conf-2016-004. INDC(JPN)-202.

[164] Yavshits S, Boykov G, Ippolitov V, et al. Multiconfiguration fission cross-sections at transitional energy region 20–200 MeV. International Atomic Energy Agency; 2001. INDC (CCP)-430. p. 83–94.

[165] Watanabe Y, Kosako K, Kunieda S, et al. Status of JENDL high energy file. J Korean Phys Soc. 2011; 59:1040–1045. doi:10.3938/jkps.59.1040.

[166] Tovesson F, Hill TS, Mocko M, et al. Neutron induced fission of $^{240,242}$Pu from 1 eV to 200 MeV. Phys Rev C. 2009;79:014613. doi:10.1103/PhysRevC.79.014613. EXFOR 14223.

[167] Tovesson F. Uncertainty quantification in fission cross section measurements at LANSCE. Nucl Data Sheets. 2015;123:124–129. doi:10.1016/j.nds.2014.12.022.

[168] Neudecker D, Cabellos O, Clark AR, et al. Informing nuclear physics via machine learning methods with differential and integral experiments. Phys Rev C. 2021;104:034611. doi:10.1103/PhysRevC.104.034611.

[169] Takano H, Hasegawa A, Nakagawa M, et al. JAERI fast reactor group constants set, Version II. Japan Atomic Energy Research Institute. 1978; JAERI 1255. doi:10.11484/jaeri-1255.

[170] Takano H, Kaneko K. Revision of fast reactor group constant set JFS-3-12. Japanese Atomic Energy Research Institute. 1989; JAERI-M 89–141. doi:10.11484/jaeri-m-89-141.

[171] Kawano T, DeCE: The ENDF-6 data interface and nuclear data evaluation assist code. J Nucl Sci Technol. 2019;56:1029–1035. doi:10.1080/00223131.2019.1637797.

[172] Cullen DE. PREPRO 2019 - 2019 ENDF/B pre-processing codes. International Atomic Energy Agency. 2019. IAEA-NDS-0229 Rev.19, August 20, 2019.

[173] Mannhart W. Evaluation of the Cf-252 fission neutron spectrum between 0 MeV and 20 MeV. In: Proceedings of an Advisory Group Meeting on Properties of Neutron Sources, Leningrad, 9–13 June 1986. International Atomic Energy Agency; 1987. p. 158–171; IAEA-TECDOC-410.

[174] Mannhart W. Status of the Cf-252 fission neutron spectrum evaluation with regard to recent experiments. In: Proceedings of a Consultants Meeting on Physics of Neutron Emission in Fission, Mito, 24–27 May 1988. International Atomic Energy Agency; 1989. p. 305–336; INDC(NDS)-220.
[175] Grundl JA, Gilliam DM. Fission cross-section measurements in reactor physics and dosimetry benchmarks. Trans Am Nucl Soc. 1983;44:353–355. EXFOR 10809,12821.

[176] Chadwick MB, Herman MB, Obložínský P, et al. ENDF/B-VII.1 nuclear data for science and technology: Cross sections, covariances, fission product yields and decay data. Nucl Data Sheets. 2011;112:2887–2996. doi:10.1016/j.nds.2011.11.002.

[177] Mannhart W. Response of activation reactions in the neutron field of californium-252 spontaneous fission. STI/DOC/010/452 International Atomic Energy Agency. 2006. p. 30–45.

[178] Gärlea I, Miron C. ΣΣ-ITN facility - Intermediate energy neutron source for reactor dosimetry. Revue Roumaine de Physique. 1981;26:643–652. EXFOR 30568.

[179] Gärlea I, Miron C, Lupu M, et al. Measuring of a few integral data in the ΣΣ neutron field. Revue Roumaine de Physique. 1978;23:409–417. EXFOR 30452.

[180] Gärlea I, Miron C, Popa F. Integral cross sections measured in Σ the Σ spectrum. Revue Roumaine de Physique. 1980;25:107–110. EXFOR 30568.

[181] Shibata K. Average cross sections calculated in various neutron fields. International Atomic Energy Agency; 2002. INDC(NDS)-435. p. 49–58.

[182] Trkov A, Griffin PJ, Simakov SP, et al. IRDFF-II: A new neutron metrology library. Cornell Univ. 2019. arXiv:1909.03362v2.

[183] Fabry A, Leeuw GD, Leeuw SD. The secondary intermediate-energy standard neutron field at the MOL-ΣΣ facility. Nucl Technol. 1975;25:349–375. doi:10.13182/NT75-A24373.

[184] Simakov SP. [Private communication with N. Otuka]. 2021.

[185] Nagaya Y, Okumura K, Sakurai T, et al. MVP/GMV Version 3: General purpose Monte Carlo codes for neutron and photon transport calculations based on continuous energy and multigroup methods. Japan Atomic Energy Agency. 2017. JAEA-Data/Code 2016-018. doi:10.11484/jaea-data-code-2016-018.

[186] Chiba G, Okumura K, Sugino K, et al. JENDL-4.0 benchmarking for fission reactor applications. J Nucl Sci Technol. 2011;48:172–187. doi:10.1080/18811248.2011.9711692.

[187] Chiba G. Nuclear data adjustment with integral data sensitive to fast neutron energy range. In: Proceedings of the 2015 Symposium on Nuclear Data, Tokai, 19–20 November, 2015. Japan Atomic Energy Agency. 2016; 117–122. JAEA-Conference 2016-004, INDC(JPN)-202. doi:10.11484/jaea-conference-2016-004.

[188] Young PG, Arthur ED, Chadwick MB. Comprehensive nuclear model calculations: Introduction to the theory and use of the GNASH code. In: Proceedings of the Workshop on Nuclear Reaction Data and Nuclear Reactors: Physics, Design, and Safety, Trieste, 15 April–17 May 1996; Vol. 1; 1998. p. 227–404.

[189] Manna A, Aberle O, Alcayne V, et al. Setup for the measurement of the 235U(n, f) cross section relative to n-p scattering up to 1 GeV. EPJ Web Conf. 2020;239:01008. doi:10.1051/epjconf/202023901008.

[190] Lisowski PW. [Private communication with T. Fukahori]. 1997.

[191] Donets AYu, Evdokimov AV, Formichev AV, et al. Neutron-induced fission cross-sections of U233, U235, U238, Th232, Pu239 and Np237 in the energy range 1–200 MeV. In: Proceedings of the Seventh International Seminar on the Interaction of Neutrons with Nuclei “Neutron Spectroscopy, Nuclear Structure, and Related Topics,” Dubna, 25–28 May 1999; 1999. p. 357–362; JINR E3-99-212. EXFOR 41455.

[192] Behrens JW, Browne JC. Measurement of the neutron-induced fission cross sections of americium-241 and americium-243 relative to uranium-235 from 0.2 to 30 MeV. Nucl Sci Eng. 1981;77:444–453. doi:10.13182/NSE81-A18957. EXFOR 10652.

[193] Capore T, Badikov S, Carlson AD, et al. Unrecognized sources of uncertainties (USU) in experimental nuclear data. Nucl Data Sheets. 2020;163:191–227. doi:10.1016/j.nds.2019.12.004.

[194] Droog M. Dealing with uncertainties - A guide to error analysis. Springer-Verlag Berlin Heidelberg; 2007.

[195] Harada H. Dēta no baratuki ni mukiau — aru kokusai kyoryoku deno hyoka katudo wo furikae [Tackling discrepancy of data: Looking back at international cooperation on data evaluation]. Kaku Dēta Nyūsu (Nuclear Data News). 2021;129:35–43. In Japanese.

[196] Salvatores M, Aliberti G, Palmiotti G. The role of differential and integral experiments to meet requirements for improved nuclear data. In: Proceedings of the International Conference on Nuclear Data for Science and Technology, Nice, 22–27 April 2007; Vol. 2; 2008. p. 883–886. doi:10.1051/ndata:07297.

[197] Salvatores M, Aliberti G, Dunn M, et al. Uncertainty and target accuracy assessment for innovative systems using recent covariance data evaluations. Nuclear Energy Agency. 2008. NEA/WPEC-26.

[198] Dupont E, Bossant M, Capore T, et al. HPRL – International laboratory to identify and monitor priority nuclear data needs for nuclear applications. EPJ Web Conf. 2020;239:15005. doi:10.1051/epjconf/202023915005.

[199] Henriksson H, Schwerer O, Rothman D, et al. The art of collecting experimental data internationally: EXFOR, CINDA and the NRDC network. In: Proceedings of the International Conference on Nuclear Data for Science and Technology, Nice, 22–27 April 2007; Vol. 2; 2008. p. 737–740. doi:10.1051/ndata:07290.

[200] Wagemans C, Schillebeeckx P, Deruyter AJ, et al. Subthermal fission cross-section measurements for 233U, 235U and 239Pu. In: Proceedings of the International Conference on Nuclear Data for Science and Technology, Mito, 30 May–3 June 1988; 1988. p. 91–95. EXFOR 22080.

[201] Blons J. High resolution measurements of neutron-induced fission cross sections for 233U, 235U, 239Pu and 241Pu below 30 keV. Nucl Sci Eng. 1973;51:130–147. doi:10.13182/NSE73-A26589. EXFOR 20001,20446,20484.

[202] James GD. Cross-sections of the heavy nuclei in the resonance region. In: Proceedings of the Second International Conference on Nuclear Data for Reactors, Helsinki, 15–19 June 1970; Vol. 1. International Atomic Energy Agency; p. 267–286. STI/PUB/259. EXFOR 22593.