Overview of the dissemination of n_TOF experimental data and resonance parameters

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Abstract. The n_TOF neutron time-of-flight facility at CERN is used for nuclear data measurements. The n_TOF Collaboration works closely with the Nuclear Reaction Data Centres (NRDC) network to disseminate the experimental data through the international EXFOR library. In addition, the Collaboration helps integrate the results in the evaluated library projects. The present contribution describes the dissemination status of n_TOF results, their impact on evaluated libraries and ongoing efforts to provide n_TOF resonance parameters in ENDF-6 format for further use by evaluation projects.

1 Introduction

The n_TOF neutron spallation source [1] at CERN is used since 2001 for high quality nuclear data measurements from thermal energy up to hundreds of MeV for the benefit of various communities in the fields of nuclear physics, nuclear astrophysics and nuclear technology. In the past twenty years, a considerable amount of valuable experimental results has been obtained and published, and measurements are still ongoing.

In line with the CERN open data policy, the n_TOF Collaboration has taken actions [2] to preserve its unique data, to facilitate access to them, and to allow their re-use by expert users. Published results, reaction yields, cross sections and resonance parameters are available in the international EXFOR library [3]. However, these results have not been fully exploited yet for the benefit of the end-users, in particular for the improvement of evaluated nuclear data libraries.

This contribution aims at updating the status and availability of n_TOF data and at presenting ongoing efforts for better integration of the results in the evaluated library projects.

2 n_TOF measurements

Until recently, the n_TOF facility at CERN operated two main experimental areas. The experimental area 1 (EAR-1) located at the end of a 180 m flight path benefits from the best possible energy resolution. The experimental area 2 (EAR-2) is only 18 m from the neutron source in order to benefit from a high instantaneous flux. Since 2021, a new experimental area (NEAR) [4] is available next to the neutron source with even higher neutron flux.

Various detector setups have been developed along the years to make the best use of the unique characteristics of the n_TOF facility. Fission measurements have been performed with fast ionization chambers, parallel plate avalanche counters and micro-mesh gaseous structure (Micromegas) detectors [5]. Capture measurements were performed with deuterated benzene (C6D6) scintillators and with the 4π Total Absorption Calorimeter (TAC) [6]. In the recent years, study of charged particle (cp) emission reactions were achieved with Si telescopes and Micromegas detectors [6].

Table 1 summarizes the number of n_TOF measurements performed for each type of reactions during the previous data collection Phases I through III; the few measurements from the ongoing Phase-IV (> 2021) are not listed.

Table 1. Number of n_TOF measurements by reaction.

	(n,γ)	**(n,f)**	**(n,cp)**
Phase-I (2001-2004)	27	18	0
Phase-II (2009-2012)	16	4	3
Phase-III (2014-2018)	30	9	9

3 n_TOF data in EXFOR

Since 2015 the datasets from the legacy backlog of the early n_TOF Phases are being compiled in the EXFOR library thanks to the involvement of the whole Collaboration [2]. Moreover, newly published results are systematically sent to the Nuclear Reaction Data Centres (NRDC) network for compilation. The data stored in EXFOR includes pointwise reaction yields and cross sections as well as resonance parameters.

Table 2 shows the dissemination status of n_TOF data. As of September 2022, all published data are available in EXFOR except for a few datasets from legacy works (6 datasets over a total of 76 datasets with a final publication). The data dissemination is closely monitored by the Collaboration and efforts are ongoing to retrieve old pointwise datasets. All information are summarized on the n_TOF public TWiki website at https://twiki.cern.ch/NTOFPublic [7].

Table 2. Dissemination status of n_TOF data (as of September 2022).

	Reaction	Datasets with a final publication	Data dissemination status*
Phase-I (2001-2004)	(n,γ)	27	85%
	(n,f)	14	100%
	All	**41**	**90%**
Phase-II (2009-2012)	(n,γ)	15	87%
	(n,f)	2	100%
	(n,cp)	3	100%
	All	**20**	**90%**
Phase-III (2014-2018)	(n,γ)	9	100%
	(n,f)	2	100%
	(n,cp)	4	100%
	All	**15**	**100%**

*Percentage of final datasets available in EXFOR

4 n_TOF data in evaluated files

A number of n_TOF measurements are motivated by needs from nuclear applications, such as the ones promoted in the High Priority Request List (HPRL) for nuclear data [8]. Whenever an evaluated file needs to be improved, all theoretical and experimental works are reviewed, including new n_TOF measurements. Table 3 shows the number of citations of n_TOF works by library projects. This number includes citations found both in the comments (MF1/MT451) of the evaluated files and in the library-release Big Papers. However, this is only an indication as, for example, n_TOF resonance parameters adopted from the Atlas of neutron resonances [9] may not be properly cited. Nevertheless, one can observe an increase over the years in the number of n_TOF citations by each library project. Moreover, a large number of n_TOF results has been cited in the JENDL-5 library (see e.g. [10]), which is the most recent and actually the first library built after n_TOF data were made widely available in EXFOR.

Further efforts are ongoing to integrate n_TOF data in TENDL and JEFF files, first using n_TOF pointwise yields and cross sections while doing a full evaluation work and second using directly n_TOF resonance parameters when relevant.

5 n_TOF resonance parameters

One of the goals of the n_TOF Collaboration is to perform relevant measurements of basic scientific data for the benefit of various user communities. In many cases the outcome includes a full R-matrix analysis of the measured data from which resonance parameters have been published. This is the case for most of the capture measurements (Mg-24,25,26, Fe-54,57, Zr-90,91, La-139, Sm-151, Gd-155,157, Tm-171, Os-186,187,188, Au-197, Pb-204,206,207, Bi-209, U-234,238, Np-237, Pu-242, Am-241,243) and for a few fission experiments (U-236, Pu-240). Although that analysis is often limited to n_TOF data alone, the resulting resonance parameters are sometimes unique and it is definitely worthwhile to consider updating the resonance region of evaluated files, especially in the case of fission products.

In addition to the parameters tabulated in the publications, the n_TOF members usually have access to additional information, including the SAMMY files used in the resonance analysis. As a result, the n_TOF Collaboration now provides resolved resonance parameters in ENDF-6 format (i.e., MF2/MT151 with LRU=1) together with the associated uncertainties. These parameter files are available on the n_TOF public TWiki website [7].

6 New evaluations using n_TOF data

Evaluation works using n_TOF data are ongoing in close collaboration with evaluators from TENDL, JEFF, ENDF and IAEA projects.

Thorough evaluation in the resonance region are performed using all available experimental data (including n_TOF results) from all reaction channels in a consistent R-matrix analysis in order to extract more accurate resonance parameters. In such cases, the evaluators use the pointwise datasets from EXFOR and the n_TOF Collaboration provides support and complementary information as needed. Such evaluations are ongoing for major isotopes such as Gd-155,157, U-234,235,238, Pu-242, Am-243.

Another type of evaluation work consists in updating the evaluated resonance parameters using more recent ones based on new accurate experimental data. Actually, this was performed routinely in most library projects for relatively minor isotopes using the parameters compiled in the Atlas of neutron resonances until 2018. The n_TOF resonance parameters now available in ENDF-6 format are intended to contribute in such a way. In close collaboration with the TENDL and JEFF project, test

evaluations are being produced for Mg-24,25,26, Fe-54,57, La-139, Sm-151, Tm-171, Os-186,187,188.

Figure 1 shows the example of the Sm-151 capture measured between 0.6 eV and 1 keV [11]. The n_TOF cross section is reconstructed with the SAMMY code for checking purposes. This is a typical example of a major fission product evaluation, whose resolved resonance region can be extended to higher energies using the n_TOF resonance parameters.

7 Summary

All n_TOF experimental data and resonance parameters are released after publication and made available in the EXFOR library.

Moreover, the n_TOF resonance parameters have been compiled in the Atlas of neutron resonances until 2018 and they are now systematically translated in ENDF-6 format for further use by the evaluation projects.

All these results (reaction yields, cross sections, and resonance parameters) are summarized and made available from the n_TOF public TWiki website at https://twiki.cern.ch/NTOFPublic.

In addition to ongoing evaluation works using pointwise data, test evaluations based on n_TOF resonance parameters have been prepared in close collaboration with the TENDL and JEFF projects.

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Table 3. Number of citations of n_TOF data in evaluated libraries.

JEFF			ENDF/B			JENDL		
3.1.1 (2009)	3.2 (2014)	3.3 (2017)	VII.0 (2006)	VII.1 (2011)	VIII.0 (2018)	3.3 (2002)	4.0u (2010+)	5.0 (2021)
0	2	6	2	3	7	0	10	23

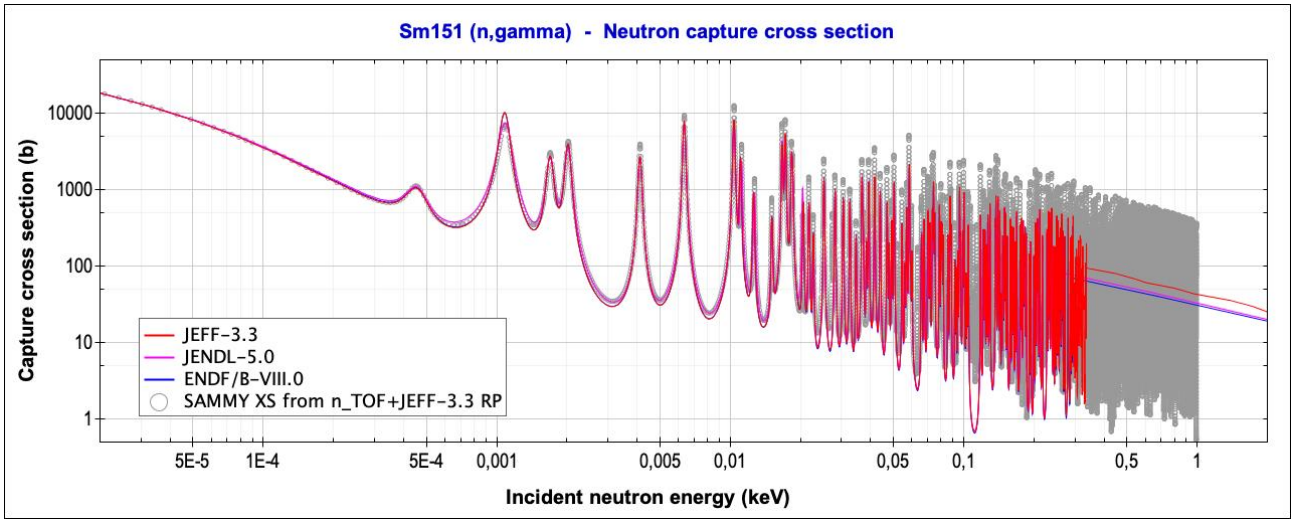

Fig. 1. Comparison between the Sm-151 capture cross section from evaluated libraries and the cross section reconstructed from the n_TOF resonance parameters with SAMMY (the resonances parameters below 0.6 eV are borrowed from JEFF-3.3 = TENDL-2015).