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Dissemination of data measured at the CERN n_TOF facility

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Abstract. The n_TOF neutron time-of-flight facility at CERN is used for high quality nuclear data measurements from thermal energy up to hundreds of MeV. In line with the CERN open data policy, the n_TOF Collaboration takes actions to preserve its unique data, facilitate access to them in standardised format, and allow their re-use by a wide community in the fields of nuclear physics, nuclear astrophysics and various nuclear technologies. The present contribution briefly describes the n_TOF outcomes, as well as the status of dissemination and preservation of n_TOF final data in the international EXFOR library.

1. Introduction

The CERN n_TOF facility [1] is used since 2001 for high quality nuclear data measurements. A considerable amount of valuable experimental results have been obtained and published, and new measurements are going on. These results are important for the end-users of nuclear data, in particular for the improvement of evaluated nuclear data libraries. In line with global standards in data preservation and Open Science, the n_TOF Collaboration takes actions to preserve its unique data, facilitate access to them in standardised format, and allow their re-use by a wide community in the fields of nuclear physics, nuclear astrophysics and various nuclear technologies for medical and energy applications. In the latter fields, all evaluated nuclear reaction libraries are built from the international EXFOR library [2], which has been successfully developed and maintained for 50 years by the International Network of Nuclear Reaction Data Centres (NRDC). Accordingly, the n_TOF Collaboration strengthened the links with the IAEA Nuclear Data Section and the NEA Data Bank to improve the dissemination and preservation of its data through the EXFOR library. The present paper describes the main n_TOF outcomes, and the status of data dissemination activities.

2. The n_TOF outcomes

The facility is based on the 20 GeV/c pulsed proton beam from CERN's Proton Synchrotron impinging on a lead spallation target. A layer of water around the spallation target moderates the initially fast neutrons down to a white spectrum of neutrons covering the full range between meV and GeV neutron energies.

During Phase-I when the first spallation target was used from 2001 up to 2004, the water coolant also served as moderator. Starting from Phase-II, after the installation in 2008 of an upgraded spallation target, the latter was enclosed with a separate cooling circuit followed by an exchangeable borated water moderator.

Since 2001, neutron induced reactions are measured in the experimental area EAR-1 [3] at approximately 185 m from the spallation source. In 2014, a second experimental area, EAR-2 [4], at about 18 m from the neutron source has been constructed for Phase-III and is offering new possibilities for demanding cross section measurements. Table 1 gives an overview of the number of measurements since 2001.

2.1. Phase-I (2001–2004) & Phase-II (2009–2012)

During the first phase from 2001 to 2004 capture and fission data for a number of isotopes have been taken. Capture measurements with C_6D_6 liquid scintillator detectors concerned both stable and radioactive isotopes of Mg, Fe, Zr, La, Sm, Os, Au, Pb, Bi, and Th. A 4π Total Absorption Calorimeter (TAC) [5] consisting of 40 BaF_2 crystals has been used for neutron capture measurements of ^{197}Au, ^{233}U, ^{234}U, ^{237}Np, ^{240}Pu, and ^{243}Am. Fission cross sections were measured with the FIC fission detectors [6] for ^{232}Th, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{237}Np, ^{241}Am, ^{243}Am, and ^{245}Cm. Other fission detectors based on Parallel Plate Avalanche Counters (PPAC) [7,8] were used in measurements of the fission cross sections of ^{nat}Pb, ^{209}Bi, ^{232}Th, ^{237}Np, ^{233}U, ^{234}U, ^{235}U and ^{238}U. The full list of measured isotopes and reactions together with the final or most relevant publication is given in Ref. [9].

During Phase-II in 2009–2012 mostly capture measurements were performed, while new PPAC were used for additional fission experiments, including the measurement of the fission-fragment angular distributions [10]. The (n,γ) reaction was investigated on additional stable and radioactive isotopes of Mg, Fe, Ni, and Zr. In order to handle unsealed, but still encapsulated, highly radioactive samples, EAR-1 was transformed in a type A laboratory. After this transformation, measurements of the capture reactions were performed for ^{236}U, ^{238}U and ^{241}Am, for the latter two with two different capture detector systems (C_6D_6 and TAC). The TAC was also used in combination with a Micromegas detector in a first attempt to measure the ^{235}U(n,γ) reaction using a veto on the fission reaction. In addition to these measurements several other techniques have been tested and the full list of the Phase-II measurements and their references are given in Ref. [9].

Table 1. Overview of the number of n_TOF measurements.

Reaction	Phase-I (2001–2004)	Phase-II (2009–2012)	Phase-III (2014–...)*
(n,γ)	27	16	12(+14)
(n,f)	18	4	6(+2)
(n,cp)	0	3	5(+1)

*The numbers between parentheses correspond to additional approved measurements, as of March 2017.

2.2. Phase-III (2014-...)

Since 2014, two experimental areas are available for capture and fission measurements, and new challenging experiments are now possible in EAR-2, such as ^{240}Pu(n,f), ^{244}Cm(n,γ), ^{246}Cm(n,γ), ^{7}Be(n,α) and ^{7}Be(n,p). The list of the 2014-2015 measurements is available in Ref. [9] and an update is given in Ref. [11].

3. Data dissemination

Publication of results is obviously essential for knowledge transfer and preservation, but this is not enough when dealing with nuclear data for applications. Indeed, these data should be usable and actually used. Hence, once the data are finalized, published and fully exploited by the n_TOF Collaboration, it is essential to make them widely available to all users.

In the field of nuclear technologies especially, the EXFOR library is known as the “Mother of all libraries” and is the ground for the development of all evaluated nuclear reaction libraries for particle transport, activation, dosimetry, standards, etc. Moreover, EXFOR has been successfully maintained for decades and is continuously updated by the NRDC network. These two reasons make EXFOR an appropriate place for both an efficient dissemination and preservation of n_TOF data.

3.1. IAEA recommendations

The IAEA organised in 2013 a meeting on EXFOR data in the resonance region and spectrometer response functions [12]. Participants agreed on recommendations and prepared templates for submission of time-of-flight spectra to NRDC. The main recommendations for experimentalists can be summarized as follows.

- Reaction yield or transmission should be reported in addition to cross sections.
- Data should be reported *vs.* time-of-flight in addition to the required neutron energy.
- Total uncertainty and uncorrelated uncertainty components should be reported separately.
- Additional information necessary to reconstruct the full covariance matrix should be reported if correlations due to data reduction are significant.
- Additional quantities of interest should be reported, such as the neutron flux distribution, energy-dependent backgrounds and correction factors, as well as the spectrometer response function to be used with the data.

3.2. Dissemination of n_TOF final data

The raw n_TOF data are available on CERN computers, whereas the final reduced data of interest to users are generally only available from the physicists doing the analysis. In order to release and preserve these final data, the n_TOF authors use the IAEA recommendations and templates as guidelines for the information to be supplied, with emphasis on data not already available in the publications.

In order to quantify the status and progress of the dissemination of n_TOF data, one should distinguish between various acceptable levels of completeness in data reporting. After publication of the final results, it is acknowledged that the necessary data to disseminate and preserve are the main experimental quantities (such as pointwise reaction yields, cross sections, cross-section ratios) and the associated statistical/uncorrelated uncertainty *vs.* energy with the best possible resolution. The status of n_TOF data available in EXFOR with this necessary information is considered as acceptable. The dissemination and preservation in EXFOR of more comprehensive datasets is obviously encouraged, and actually done on a case-by-case basis, depending on the end-use of the data and interactions with expert users such as evaluators.

Figure 1 and Table 2 illustrate the excellent data dissemination status of n_TOF data for fission. It shows the strong commitment of the fission team, which took the initiative early 2015 to make these data widely available to the nuclear data community.

Figure 2 shows the progress for the dissemination of capture data measured during Phase-I. The situation is not as satisfactory as for fission yet, essentially because capture measurements were performed by different teams, which partly turned to other activities along the different

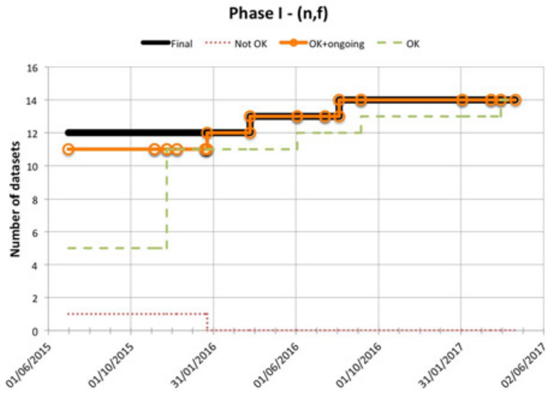

Figure 1. Evolution of data dissemination for Phase-I fission data. "Final" corresponds to datasets with a final publication; "OK" to datasets available in EXFOR with all necessary data; "OK + ongoing" includes also datasets under compilation by NRDC.

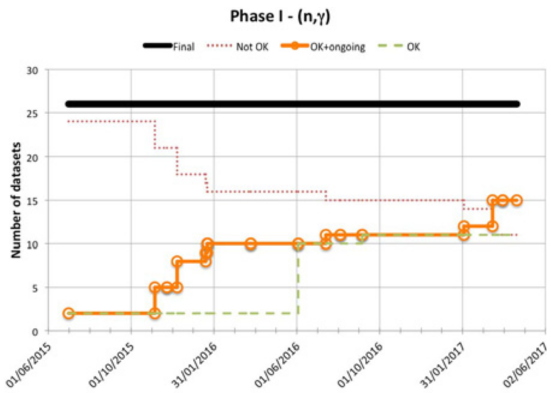

Figure 2. Evolution of data dissemination for (n,γ) data (Phase-I). See Fig. 1 for explanation of the legend.

n_TOF phases. Nevertheless, the situation is improving and contacts have been established with authors in order to retrieve old data and complement current EXFOR entries.

Table 2 shows the global dissemination status of n_TOF data, as of March 2017. Overall, 75% of the datasets with a final publication are available in EXFOR with an acceptable status, i.e., all necessary data available. The current objective is to reach dissemination values higher than 80% for all reactions and phases. This should be possible thanks to ongoing efforts to retrieve as much as possible Phase-I capture yields from backups.

4. Outlook

Experimental data are useful and unique, accordingly they must be usable, actually used, and preserved. In order to improve the usability and long-term preservation of n_TOF outcomes, the data dissemination is continuously monitored: new data are systematically released after the final publication, whereas the backlog of final data not available is being reduced. This is made possible thanks to an improved organisation for the data dissemination, and of course to the involvement of the whole n_TOF Collaboration, especially for the retrieval of old datasets. A list of measurements since 2001 is available on the n_TOF public TWiki webpage [13]. That list includes detailed information on the measured reactions: n_TOF phase, experimental area, detectors, energy range, data status (preliminary or final), main publications and corresponding EXFOR entries.

Table 2. Dissemination status of n_TOF data as of March 2017.

n_TOF phases	Reaction	Datasets with a final publication	Data dissemination status*
Phase-I (2001–2004)	(n,γ)	26	58%
	(n,f)	14	100%
	All	**40**	**73%**
Phase-II (2009–2012)	(n,γ)	7	71%
	(n,f)	2	100%
	(n,cp)	2	100%
	All	**11**	**82%**
Phase-III (2014–...)	(n,cp)	1	100%

*Percentage of final datasets with all necessary data already available in EXFOR or under compilation by NRDC.

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