STATUS REPORT OF THE N_TOF FACILITY AFTER THE 2ND CERN LONG SHUTDOWN PERIOD

N. PATRONIS for the n_TOF collaboration
European Organization for Nuclear Research (CERN)
Geneva, Switzerland
and
Department of Physics, University of Ioannina
Ioannina, Greece
Email: npatronis@uoi.gr

Abstract

During the second long shutdown period of CERN, several upgrade activities took place at the n_TOF facility. The most important ones where the replacement of the lead spallation target with a next generation liquid nitrogen cooled lead target and the establishment of a new experimental area at a very short distance from the target. In this contribution, the core commissioning actions are described along with very preliminary results. Furthermore, some indicative current and future measurements are briefly reported.

1. INTRODUCTION

The neutron time-of-flight (n_TOF) facility is based on the idea of Carlo Rubbia [1] of establishing a high intensity neutron source at CERN by taking the advantage of the on-site accelerator complex. The facility became operational in 2001. The motivation for the construction of this neutron time-of-flight facility was the deduction of high accuracy nuclear data for energy applications [2] and nuclear astrophysics studies [3].

In particular, a main activity at the n_TOF facility is to obtain nuclear data relevant for the development of innovative systems for energy production and nuclear waste transmutation, through accelerator-driven systems (ADS) and Generation IV fast neutron reactors [4]. High accuracy, high precision and high-resolution cross section data are needed, in a wide energy range, for a variety of major and minor actinides [5], as well as for coolant, spallation and structural materials [6]. Considering also that all the chemical elements of the cosmos, heavier than iron, are mainly produced through neutron capture reactions the second major branch of scientific research within n_TOF is oriented to the study of neutron induced reactions of astrophysical interest [3].

Since its first year of operation and up to the year 2018, the n_TOF facility went through different phases of operation as defined by significant upgrades/milestones. During the 2nd long shutdown period of CERN (LS2), several upgrade actions of the n_TOF facility were realized. Within this contribution, the upgrade activities of the facility will be briefly described along with the performed commissioning activities.

2. THE N_TOF FACILITY

The neutron production at n_TOF is based on spallation reactions induced by 20 GeV proton pulses delivered from the CERN Proton Synchrotron (PS) with a nominal intensity of 7 - 8 × 10^{12} protons/pulse. The maximum repetition rate of the delivered proton pulses is 0.8 Hz while the time width of each pulse is 7 ns (rms) allowing for excellent energy resolution, even in the GeV neutron energy region.

Fig. 1 shows a layout of the facility with the two established experimental areas: Experimental Area 1 (EAR-1), located at the end of a horizontal 185 m long flight path, was commissioned in 2001 and is used for measurements requiring very high neutron energy resolution. The recently commissioned (2014) vertical Experimental Area 2 (EAR-2) is located at a much shorter distance of 19 m, providing high neutron flux for measurements on small and/or radioactive samples. In both experimental areas, charged particles are removed by the corresponding "sweeping magnets" while the beam aperture is defined through two collimators and other additional shielding elements. In this way, well defined and well-shaped neutron beams result along with low background conditions. The main characteristics of the two experimental areas of the n_TOF facility are summarized in Table 1.

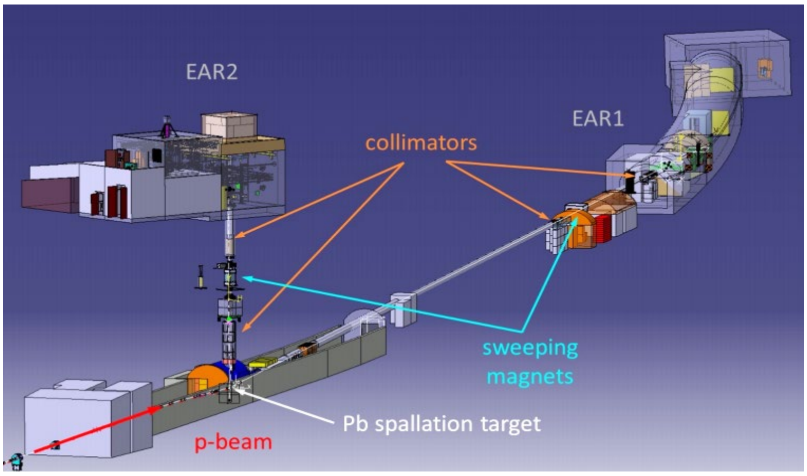

FIG. 1. The layout of the n_TOF facility at CERN. The proton beam, the lead spallation target and the main components of each beam line are presented

TABLE 1. MAIN CHARACTERISTICS OF THE EXPERIMENTAL AREAS OF THE n_TOF FACILITY

	EAR 1	EAR 2
Energy range	10 meV – 1 GeV	10 meV - 100 MeV
Energy resolution	$10^{-4} – 10^{-2}$	$10^{-3} – 10^{-2}$
The two options of neutron beam collimator ∅ (cm)	1.8/8.0	3.0/6.7
Neutrons/pulse for each neutron beam collimation option	5.5×10^5 / 1.2×10^7	2.2×10^7 / 2.0×10^8

3. UPGRADE ACTIONS DURING LS2

During the CERN 2nd Long Shutdown period (LS2) within the years 2019-2020 several upgrade activities were realized at the n_TOF facility leading to a successful transition into its 4th phase of operation.

The most important upgrade (action) was the replacement of the lead spallation target that served the facility for more than ten years with a new target. The new spallation target is a sliced, liquid nitrogen cooled lead target. More details on the new lead spallation target can be found in [7].

The second major development during the LS2 period was the establishment of a new experimental area located at about 3m distance on the side of the lead spallation target aiming mostly to neutron activation studies. This new experimental area, named as NEAR station [8], offers a much higher neutron flux than EAR1 and EAR2. The enhanced neutron flux is instrumental when limitations on the sample mass are imposed, as for instance when radioactive samples are considered. In the activation area of the NEAR Station, nuclear astrophysics measurements are foreseen after appropriate filtering of the neutron beam towards quasi Maxwellian shaped energy distributions that correspond to different stellar temperatures. The proof-of-principle of beam energy filtering using B4C filters is one of the approved and running experiments of the n_TOF 2022 campaign [9]. Besides the NEAR activation area, the irradiation NEAR sub-area is also operational, with material irradiation hardness studies taking place already in 2022. In this sub-are the samples are placed in specially designed air-tight holders and the handling of the samples is performed by a robot.

Besides the aforementioned major upgrade actions, several additional significant developments of the n_TOF facility took place during LS2. For instance, the collimator system of EAR1 was replaced with a new one that allows much faster exchange between different beam apertures. Furthermore, the EAR1 beam line sweeping electromagnet was replaced by a permanent magnet allowing stable operation and zero energy consumption.

Moreover, in addition to upgrades improving the neutron beam characteristics, the n_TOF teams took advantage of the LS2 period to develop, characterize and to deliver innovative detection setups (e.g. [10, 11]) that provide the ability to perform a new series of measurements and to investigate previously unexplored physics cases.

4. COMMISSIONING ACTIVITIES AFTER LS2

Given the important upgrades during LS2, the neutron beams of both TOF experimental areas (EAR1 & EAR2) of the n_TOF facility were commissioned thoroughly. For this purpose, different detection setups were utilized. Concerning the flux determination, ^{235}U(n,f), ^{10}B(n,a) and ^{6}Li(n,α) where used as reference reactions by applying different setups as given in Table 2 and depicted in Fig.2 and Fig. 3. Besides the neutron beam flux, the beam spatial profile was determined by means of the position sensitive PPAC detectors and by 3x3 mm Timepix detectors [12]. The neutron energy resolution was studied by measuring well known neutron resonances of different neutron capture reactions using liquid scintillation C_6D_6 γ-ray detectors. The detection setups and the corresponding reference reactions that were used are summarized in Table 2.

The analysis of the commissioning data is ongoing. Preliminary results show that in EAR1 the neutron flux is not very different with respect to the previous phase, while for EAR2 a significant increase in the neutron flux is expected along with much smoother neutron energy distribution and improved neutron energy resolution.

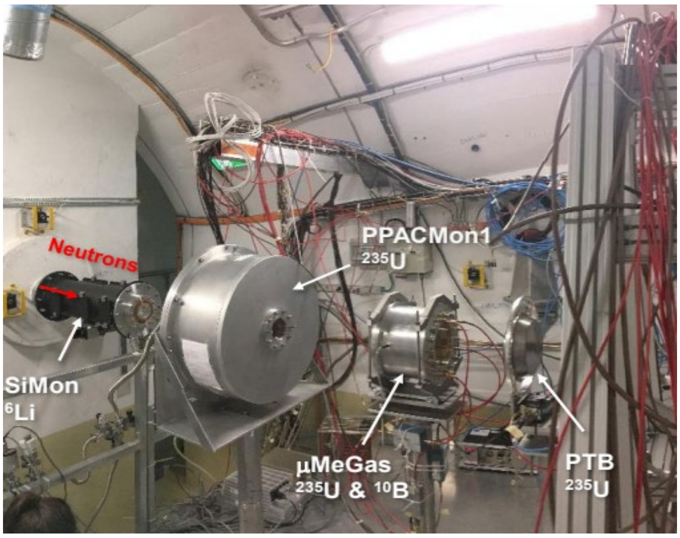

FIG 2. The EAR1 flux measurement setup. The four detection setups along with the adopted reference sample can be seen.

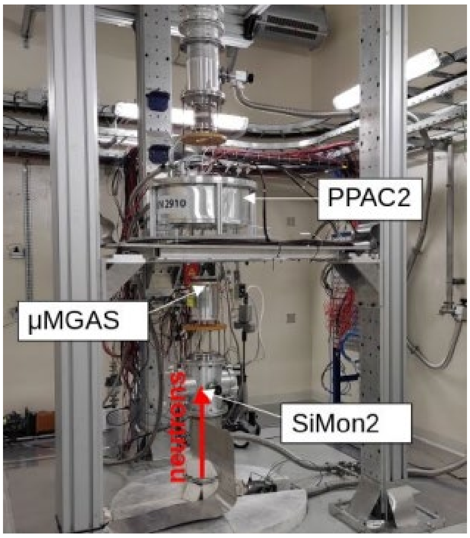

FIG 3. The EAR2 flux measurement setup. The three detection setups can be seen.

TABLE 2. ADOPTED EXPERIMENTAL SETUPS & METHODS FOR THE n_TOF PHASE 4 COMMISSIONING

Detector	EAR 1	EAR 2
Micromegas/flux	^{235}U(n,f), ^{10}B(n,α)	^{235}U(n,f), ^{10}B(n,α)
PPAC/flux& beam profile	^{235}U(n,f)	^{235}U(n,f)
Silicon Monitor/flux	^{6}Li(n,α)	^{6}Li(n,α)
PTB fission chamber [17]/flux	^{235}U(n,f)	---
C_6D_6/resolution function	^{197}Au(n,γ), ^{nat}Ir(n,γ), ^{nat}Fe(n,γ), ^{nat}Si(n,γ)	^{197}Au(n,γ), ^{nat}U(n,γ), ^{nat}Ir(n,γ), ^{nat}Fe(n,γ), ^{77}Se(n,γ)
TimePix	PE for n,p conversion	PE for n,p conversion

5. CONCLUSIONS AND OUTLOOK

During the 2nd Long Shutdown period of CERN, significant upgrade actions of the n_TOF facility were successfully accomplished, with the most important ones being the replacement of the lead spallation target with a new one and the establishment of the NEAR station. These significant changes define the starting point of the 4th Phase of operation of the n_TOF facility. Thanks to the development of innovative detection setups [10,11], the experimental investigation of previously unexplored physics cases becomes feasible (e.g., ^{79}Se(n,γ)[13]). In current and future experimental campaigns, an ambitious physics program is being realised, including nuclear astrophysics studies, fission reaction measurements (e.g. ^{243}Am(n,f) [14]), detector development and proof-of-principle studies (e.g. [15], [16]).

REFERENCES

[1] C. RUBBIA et al., CERN-LHC-98-002-EET, CERN, Geneva, 1998.
[2] M. SALVATORES, J. Nucl. Sci. Tech. Suppl. 2 (2002) 4-12.
[3] N. COLONNA et al., Eur. Phys. J. Web of Conf. 165 (2017) 01014.
[4] G. ALIBERTI et al., Ann. Nucl. Energy 22 (2006) 700-733.
[5] N. COLONNA et al., Eur. Phys. J. A 56 (2020) 48.
[6] F. GUNSING et al., Eur. Phys. J. Plus 131 (2016) 371.
[7] R. ESPOSITO et al., Phys. Rev. Acc. And Beams 24 (2021) 093001.
[8] M. FERRARI et al., arxiv.org, arXiv:2202.12809v2 (2022), arXiv:2202.12809v2
[9] M. E. STAMATI et al., CERN-INTC-2022-008 ; INTC-P-623 (2022), https://cds.cern.ch/record/2798978
[10] V. BABIANO et al., Eur. Phys. J. A 57 (2021) 197.
[11] C. DOMINGO-PARDO, Nucl. Instr. And Methods in Phys. Res. A 825 (2016), 78
[12] X. LlOPART et al., Nucl. Instr. And Methods in Phys. Res. A 581 (2007), 485
[13] V. BABIANO et al., CERN-INTC-2020-065 ; INTC-P-580 (2020), https://cds.cern.ch/record/2731962
[14] N. PATRONIS et al., CERN-INTC-2020-048 ; INTC-P-566 (2020), https://cds.cern.ch/record/2730930
[15] M. BARBAGALLO et al., CERN-INTC-2021-025 ; INTC-I-230 (2021), https://cds.cern.ch/record/2765698
[16] L. COSENTINO et al., CERN-INTC-2022-019 ; INTC-P-629 (2022), https://cds.cern.ch/record/2809189
[17] D.B. GAYTHER, Metrologia 27 (1990), 221