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Letter of Intent to the ISOLDE and Neutron Time-of-Flight Committee

Measurement of the radiation background at the n_TOF NEAR facility to study the feasibility of cyclic activation experiments

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Abstract:

Cyclic activation experiments allow the measurement of capture cross sections of isotopes with unstable (n,γ) products with short half-lives of the order of several seconds. Such short half-lives require an almost instantaneous measurement after irradiation. Thus an active detector is required in close proximity to the irradiating beam resulting in a significant level of background posing a challenge for such experiments. The n_TOF NEAR facility offers an interesting opportunity for such experiments due to its low repetition rate, intense neutron flux and wide neutron energy spectrum. So far the background conditions at NEAR have been estimated with Monte Carlo simulations but measurements are required to validate the neutron and γ-flux, and thus allow an evaluation of the feasibility and design a potential future cyclic activation station. Thus we propose to characterize the neutron and γ-ray radiation field in the n_TOF NEAR facility at several positions of interest with active and passive detection systems.

Requested protons: 7×10^{17}.
Experimental Area: NEAR

1 Introduction

The newest addition to the experimental capabilities of the n_TOF facility is its recently build NEAR station. It allows to perform various challenging measurements for different applications [1] with an intense neutron beam at a distance of 2.5 m from the lead spallation target. Among the proposed applications, it is very well suited to perform activation measurements on extremely small mass samples and on radioactive isotopes, in particular neutron capture (n,γ) cross-section measurements for nuclear astrophysics. In the case of the s-process branchings, TOF measurements are limited by the background induced by the sample activity or because sufficient amounts of isotopically pure samples are unavailable [2].
First calculations indicate that, with a suitable choice of moderator, a Maxwellian-like neutron spectrum at stellar temperatures (from a few keV to a few hundreds of keV) can be generated [3]. The first benchmark of the feasibility to measure such so-called spectrum averaged capture cross sections (SACS) at stellar temperatures [3] will be carried out this year. In this campaign the samples will be irradiated/activated for several days to weeks and transported to and measured in a high-resolution γ-ray spectrometer, usually a high purity Germanium detector (HPGe), far outside the NEAR bunker. This activation scheme consisting of a single long irradiation followed by offline decay measurements is best suited for (n,γ) measurements with long-lived unstable product isotopes (i.e. $T_{1/2} \gtrsim$ hours). The classic offline measurement irradiation scheme, described above, thus imposes an intrinsic limit on the accessible physics cases at NEAR, specifically on the minimum half-life of the (n,γ) product, given by the required time to cool down the NEAR bunker and transport of the sample to the offline detector. This limitation can be overcome with a cyclic activation scheme, i.e. repetition of short irradiation, rapid transport to a detector, measuring the decay and transport back to the irradiating beam. Depending on the duration of the transport of the sample to the detector half-lives of the order of seconds become accessible. This process is repeated for a number of cycles, and with the cyclic activation analysis (CAA) technique [4] the spectra from each counting cycle are summed together to give one final total spectrum. By means of this approach, the counting statistics for short-lived nuclides of interest can be considerably increased. A non-exhaustive list of potential interesting physics cases is given in Table 1. Among the listed cases, some would serve as benchmarks of the technique since the point-wise cross section has been already measured via TOF at n_TOF or in other facilities, others are stable samples taken from the list of Ref. [4], and a last group includes more challenging cases of astrophysical interest.
The feasibility of a future CYLCIc activation station for (N,G) experiments (CYCLING) at NEAR will depend on various factors. Firstly, the time between consecutive pulses of the proton and hence the neutron beam is given by the CERN accelerator complex ($\leqslant 0.8$ Hz), would provide periods between consecutive pulses of up to various seconds.

Target isotope	(n,γ) product $T_{1/2}$	Description
^{74}Ge	82.78 m	stable target, TOF at EAR1
^{80}Se	18.45 m	stable target, TOF at EAR1
^{205}Tl	4.199 m	stable target, TOF at EAR1
^{99}Tc	15.8 s	long-lived target, TOF at ORNL
^{109}Ag	24.6 s	stable target, sample available [4]
^{103}Rh	42.3 s	stable target, sample available [4]
^{19}F	11.00 s	stable target, challenging [8]
^{60}Fe	5.98 m	long-lived target, challenging [8]
^{137}Cs	33.41 m	unstable target
^{132}Te	12.5 m	short lived target

Table 1: Non exhaustive list of potential interesting physics cases with half-lives too short for a standard irradiation scheme at n_TOF NEAR.

This condition is well suited for the measurement of the decay of very short-lived isotopes. Secondly, the technique employs an active detector (e.g. HPGe) in the harsh radiation environment in the NEAR bunker and thus the design of the measuring station poses a substantial challenge due its close proximity to the spallation target and an excellent knowledge of the expected neutron and γ-ray fields is a prerequisite for its feasibility.

We propose the characterization of the mixed neutron-gamma radiation field at several positions in the NEAR bunker to validate first simulation results, described in Sec. 2, as a first milestone in the development of CYCLING. For this purpose we are planning to use various passive and active detection systems able to withstand the harsh environment and able to detect neutrons and γ-rays. The measurements aim to characterize not only the radiation during the main proton/neutron pulse but also to monitor levels of activation of the ambient air volume and the shielding elements at NEAR and the development over time, i.e. after a pulse and/or with beam-off, which is more difficult to simulate accurately. Potential detectors as well as the proposed experimental campaign are discussed in Sec. 3.

2 Experimental conditions at n_TOF NEAR

The technical design and characteristics of NEAR are described in [5]. The neutron beam enters in the NEAR through a collimator in the mobile shielding wall. The first characterization measurements of the neutron beam at the collimator exit have been performed in 2021 (analysis ongoing) via the passive multiple foil activation method and with the moderation-absorption technique employing activation samples (Au) at different positions inside a block of polyethylene [1]. The incoming neutrons finally impinge in the concrete wall (and soil) of the NEAR station located at 3 m downstream from the collimator. Currently no beam dump is installed to catch the beam and avoid back-scattering of neutrons. In addition to neutrons, a high fluence of γ-rays and charged

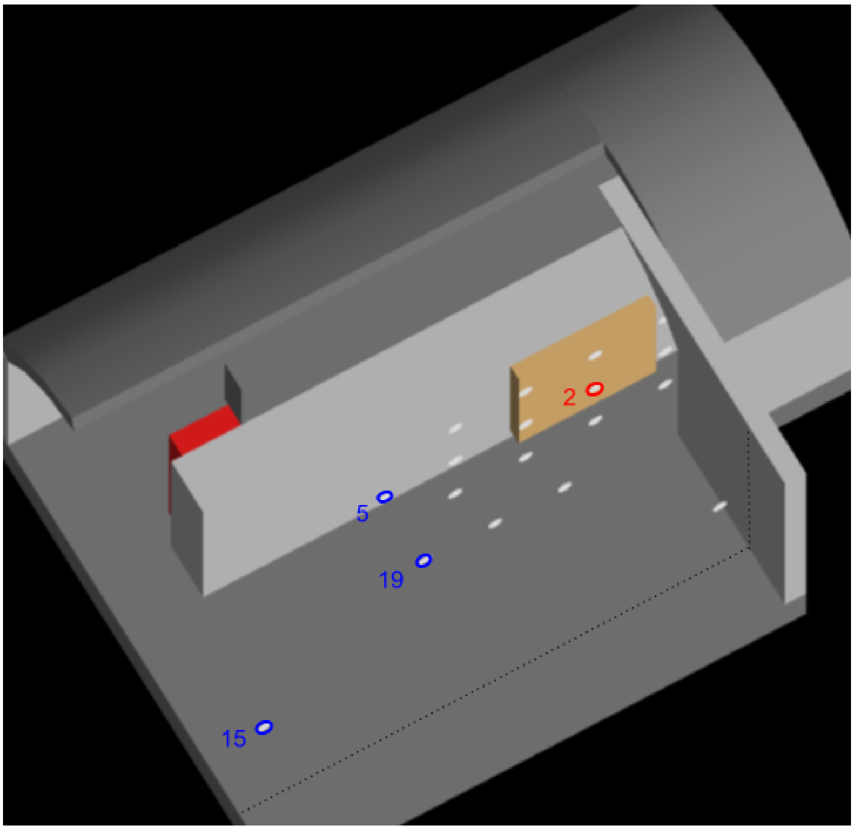

Figure 1: General view of the NEAR geometry model as implemented in Geant4. The neutron fluence has been registered in the scoring planes distributed the experimental hall. Scoring planes relevant in the forthcoming discussion and are highlighted.

particles is also expected.

As the first step in the preparation of the experimental campaign, we have carried out Monte Carlo simulations of the expected neutron fluence at various positions of the NEAR station. The first step, carried out by means of the FLUKA code, comprises the full simulation of the neutron production process in the n_TOF spallation target and the transport of the generated neutrons up to a scoring surface placed at the exit of the collimator to the NEAR station. The second step of the simulations has been carried out with the Geant4 toolkit (v10.6 p.03). For this purpose, the geometry model of the NEAR area from the shielding wall was implemented (see Fig. 1). For an accurate simulation of the neutron transport, neutron-induced reactions below 20 MeV are simulated by means of the G4NeutronHP package. Last, we have also considered the Geant4 built-in special treatment of the Thermal Scattering of neutrons below 4 eV. The latter is important for an accurate simulation of the scattering in the concrete walls of the NEAR station.

The neutron fluence has been evaluated in different scoring planes indicated by the disks in Fig. 1. In Fig. 2 we compare the maximum fluence at NEAR, obtained in scorer #2 at the exit of the collimator (highlighted in red in Fig. 1), with the three off-beam positions providing the lowest fluences (blue in Fig. 1). The experimental fluences at EAR1 [6] and EAR2 [7] have been included as a reference. The comparison indicates that the

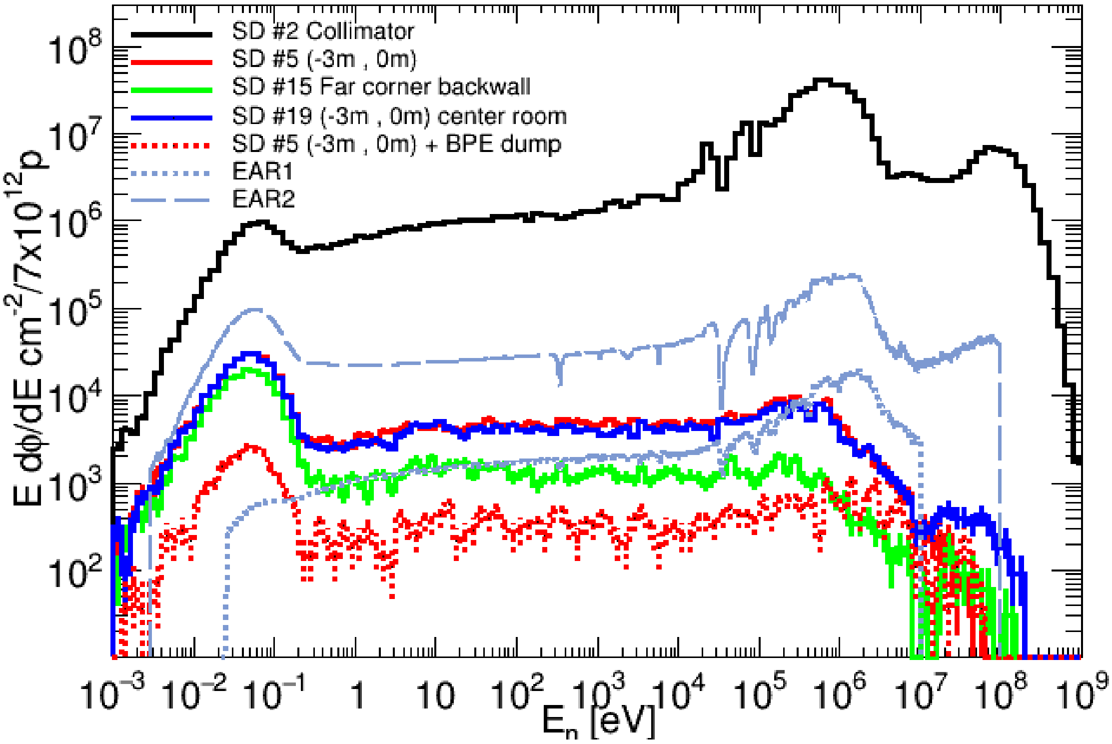

Figure 2: Comparison of the neutron fluences of the n_TOF beam lines (EAR1/2 and NEAR) as well as the simulated neutron background at several positions outside of the neutron beam at NEAR (see text for details). The neutron fluence in scorer #5 after installing a BPE dump is shown as a red dashed line.

initial conditions at NEAR without a beam dump lead to an off-beam neutron fluence which is, depending on the location, comparable to the first (EAR1) and second (EAR2) experimental area of n_TOF. In contrast to the in-beam fluence, the off-beam spectra are dominated by the back-scattered neutrons, typically below the 10 MeV range and feature an enhanced thermal component.

The installation of a borated polyethylene (BPE) beam dump with a total volume below 1 m^3, and located in front of the collimator exit and just after the activation position (i.e. at about 15 cm from the marble wall) would help to reduce the neutron fluence in the off-beam positions by about a factor of 10 with respect to the original situation, as it is illustrated with SD #5 in Fig. 2. This significant improvement would facilitate the use of active neutron detectors to characterize the off-beam flux as well as γ-ray detectors to evaluate the conditions for the installation of a measuring station.

3 Proposed setup

The characterization of the neutron and γ-ray field in positions of interest for the design of CYCLING station will be carried out with different active and passive detectors. The foreseen detection systems and their expected information is summarized in Table 2. Multiple CR39 dosimeters will be put in several positions simultaneously whilst for the active type detection systems usually only one is available, thus they will be moved during the course of the measurement, which will require interventions.
Some of the foreseen detection systems and sensor sizes are not optimized for their application at NEAR and will not be able to achieve ideal results, but will nevertheless yield interesting information to cross-check the performance of the other detectors. Some of the detection systems of Table 2 would perform much better in a shielded environment combined with the presence of a beam dump to reduce the neutron fluence as discussed in Sec. 2. However, the design and installation of the dump will not be ready for the campaign proposed in this Letter of Intent. Before we install the dump, we plan to explore the neutron and γ-ray fluxes in several off-beam positions (e.g. SD#5) with and without cadmium shielding, suppressing the dominant thermal neutron component. The conclusions of these measurements will shed light on the conditions of the NEAR and help in the optimization of the dump design and shielding elements. Moreover, after the future installation of the dump, a direct comparison of the performance of the same detectors will provide valuable information.

system	type	sensitivity		comment
		neutrons	γ-rays	
CR39	passive	thermal / fast	no	-
Diamond	active	thermal – fast	yes	n/γ discrimination
TARAT	active	fast	yes	n/γ discrimination and energy resolved
$LaBr_3$	active	no	yes	potential final detector
BC501	active	fast	yes	n/γ discrimination
^{3}He3	active	thermal – fast	no	-

Table 2: List of potential detection systems to be employed in the characterization of the neutron and γ-ray background at n_TOF NEAR.

Whilst we are not worried about insufficient statistics and low counting rates, we request for this campaign 7×10^{17} protons in order to sufficiently irradiate the passive dosimeters, deal with unexpected but also foreseeable issues, i.e. the so-called γ-flash, and to ensure a good data collection with the active detectors. In any case, this measurement is parasitic to other NEAR activities and will therefore not disturb the ongoing irradiations.

Summary of requested protons: 7×10^{17}.

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