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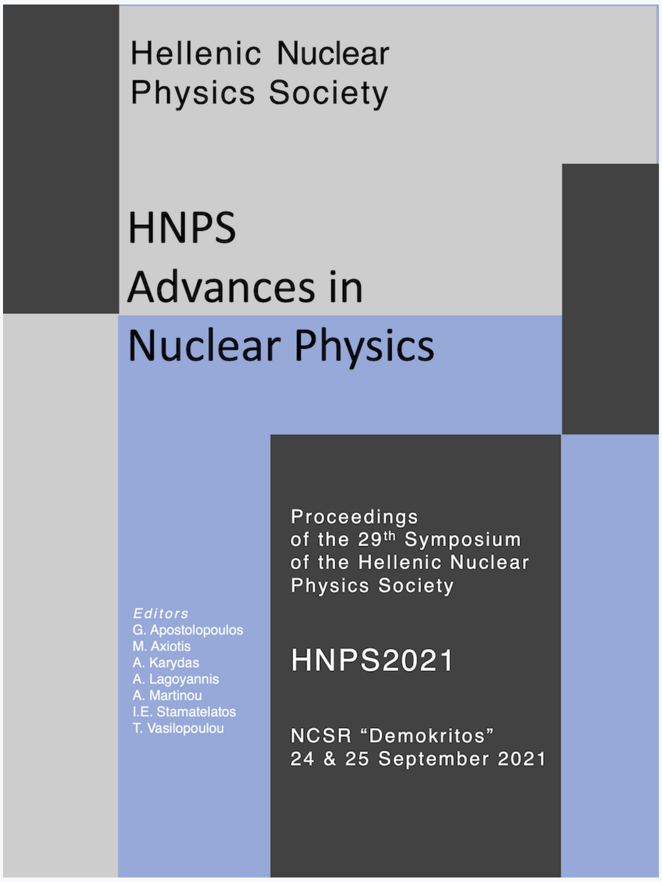

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NEAR at n_TOF/CERN: Preparing the first multi-foil activation measurement

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Abstract The n_TOF facility at CERN is a neutron Time-Of-Flight facility based on a spallation neutron source. During the Second Long Shutdown (LS2), a new experimental zone was designed and delivered. This new experimental area - the NEAR station - is located very close to the lead spallation target, at a distance of just ~3m. In this way, the high luminosity of the n_TOF neutron spallation source can be fully exploited. Towards the characterization of the new experimental area as well for the benchmarking of the performed simulations, the multi-foil activation measurement will be implemented. Eleven threshold and seven capture reference reactions will be utilized for the unfolding of the NEAR neutron beam energy spectrum that stretches from the meV to the GeV region.

Keywords NEAR Station, Neutron Activation Analysis, n_TOF, CERN

INTRODUCTION

The neutron *Time-Of-Flight* (n_TOF) facility of the European Organization for Nuclear Research (CERN) is a spallation neutron source, based on the CERN Proton Synchrotron (PS) accelerator. The PS 20GeV/c proton beam impinges on the n_TOF lead spallation target, leading to the production of 300 neutrons per proton. The short time-width and the high intensity of the delivered proton pulse is ideal for high accuracy TOF measurements. For this reason, two experimental areas at different flight paths are already operational: The EAR-1 at 185 m distance from the lead target and EAR-2 at 19 m distance. During the second Long Shutdown (LS2), in which the replacement of the Pb target with a nitrogen-cooled system was completed, the NEAR Station was built in a close geometry· approximately at a distance of 3 meters from the spallation target [1]. The new experimental zone aims to exploit the high neutron flux mainly for nuclear astrophysics purposes and measurements of MACS (Maxwellian Average Cross Sections) as well as for cross-section measurements in short-lived low-mass radioactive samples by means of the activation technique [2].

Prior to the application of the corresponding beam filters that shape the neutron beam into different temperature Maxwellian spectra, the careful characterization of the NEAR neutron beam has to be done so as to benchmark, and possibly even improve, the existing FLUKA [3] simulation results with respect the neutron beam flux and energy distribution.

Within this contribution we report on the preparation and on the experimental details of the NEAR beam characterization.

EXPERIMENTAL METHOD

For the characterization of the neutron beam at NEAR Station the multifoil activation technique will be used. Eleven threshold and seven capture reference reactions will be utilized for the unfolding of the NEAR neutron beam energy spectrum that spans the energy region between meV and GeV. The adopted reference reactions are summarized in Table 1.

Table 1. Adopted reactions for the multifoil activation technique.

^{114}Cd (n, g) ^{115}Cd	^{209}Bi (n, 3n) ^{207}Bi	^{59}Co(n, 2n) ^{58}Co
^{45}Sc (n, g) ^{46}Sc	^{209}Bi (n, 4n) ^{206}Bi	^{59}Co(n, 3n) ^{57}Co
^{176}Lu (n, g) ^{177}Lu	^{209}Bi (n, 5n) ^{205}Bi	^{197}Au (n, g) ^{198}Au
^{59}Co (n, g) ^{60}Co	^{58}Ni (n, p) ^{58}Co	^{197}Au (n, 2n) ^{196}Au
^{186}W (n, g) ^{187}W	^{58}Ni (n, 2n) ^{57}Ni	^{197}Au (n, 3n) ^{195}Au
^{113}In (n, g) ^{114m}In	^{27}Al (n, a) ^{24}Na	^{197}Au(n, 4n) ^{194}Au
^{209}Bi (n, g) ^{210}Bi		

As is depicted in Fig.1 the excitation functions of the adopted reactions cover almost the full energy range of the expected NEAR-beam energy distribution with different resonances and threshold values spread over a wide energy range. The differences between the excitation functions are instrumental for the proper unfolding of the NEAR-neutron-beam energy distribution. The capture reaction resonances will be used for the characterization of the low energy part of the expected neutron energy spectrum while the variety of the different threshold reactions will be used for the mapping of the high energy part of the neutron beam energy distribution. The neutron flux (Fig. 2) has been calculated via FLUKA [3] simulations and it has been used to define the irradiation details as well as for the estimation of the expected counting rates and activities.

The time duration of the irradiations will be ~3 weeks. The allocated number of protons for this irradiation is 1.9E+18 protons. Following the irradiation, a cooling-waiting time of 5 h will be applied, mainly for radioprotection purposes.

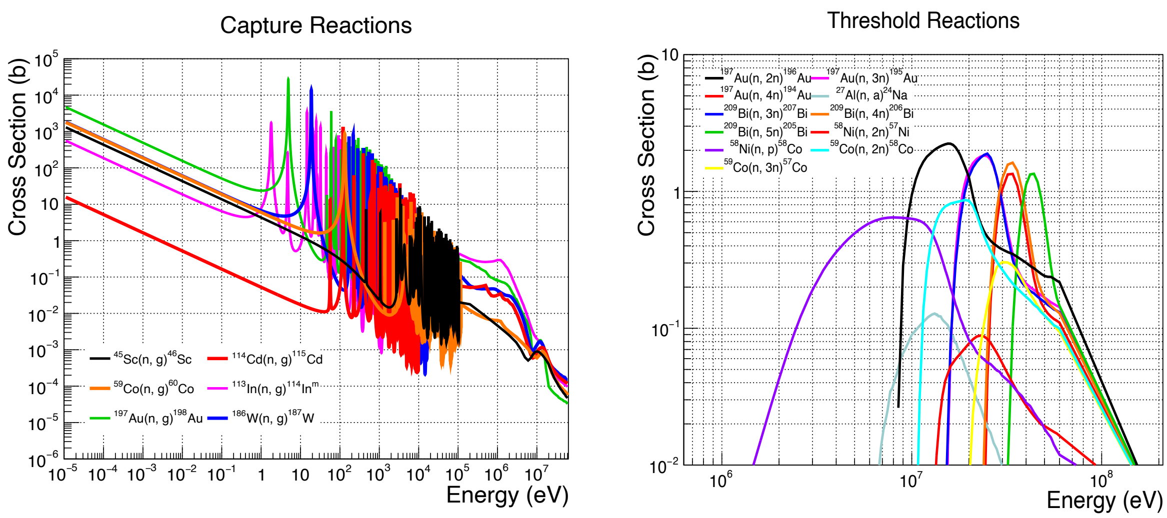

Figure 1. *Capture cross-sections which were used for the characterization of the neutron flux (left) and the threshold cross sections for the determination of the high neutron energy spectrum (right).*

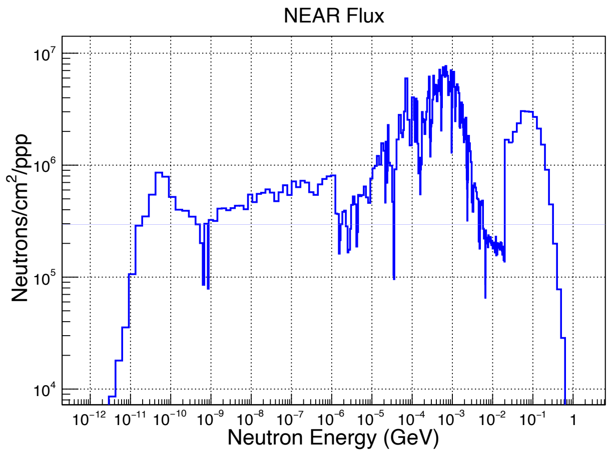

Figure 2. *The expected neutron flux at NEAR Station.*

During the irradiation, the samples will be positioned on the central part of the neutron beam (expected spatial profile). For this reason, all the samples will be placed inside a disk of 4 cm in diameter. Two different diameters of samples will be used: 3mm and 13 mm. In order to accommodate the largest possible number of samples, two sample holders will be placed in the NEAR beam, one behind the other (upstream and downstream). The details on the masses of the foils, as well as the irradiation sample configuration, are given in Table 2 and Fig. 3 respectively.

Table 1. *Information related to each sample will be placed in Al-holder.*

Sample ID	Thickness [mm]	Diameter [mm]	Purity [%]	Mass [gr]	Up | Down
In	0.5	13	99.999	0.4675 ± 0.0002	Up
Sc	0.3	3	99	0.0073 ± 0.0001	Up
W-3	0.5	12.7	>= 99.9	1.2349 ± 0.0001	Up
Bi	1	13	99.999	1.1070 ± 0.0003	Up
Cd	1	12.7	99.95	1.0714 ± 0.0002	Up
Au-1	0.5	3	99.99	0.0709 ± 0.0002	Up
Au-2	0.5	3	99.99	0.0712 ± 0.0003	Up
Co	0.5	3	99.99+	0.0348 ± 0.0001	Down
Al	0.45 - 0.55	13	99.999	0.1694 ± 0.0003	Down
Ni	0.5	13	99.98	0.5624 ± 0.0001	Down
Au-3	0.1	3	99.99	0.0142 ± 0.0003	Down
Au-4	0.1	3	99.99	0.0149 ± 0.0003	Down
Aub-backup	0.1	3	99.99	0.0148 ± 0.0002	Down
Au-6	0.025	13	99.99	0.0550 ± 0.0002	Down
Holder & Screws				38.4128 ± 0.0002	

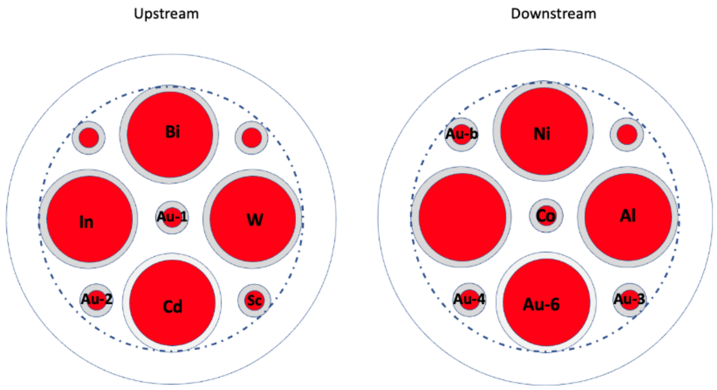

Figure 3. *The samples configuration in the upstream and downstream holder.*

The estimated activity of the experimental set-up was calculated before the experiment, via a ROOT [4] script that allowed the proper folding of the complicated excitation functions (resonances) with the expected neutron beam energy distribution. The results of these ROOT calculations are presented in Table 3.

Following the irradiation, the induced activity of each sample will be measured by means of the n_TOF HPGe detector with a 27% relative efficiency. The HPGe detector has been fully characterized in the past [5]. For the present campaign the efficiency calibration was confirmed at the adopted source-to-detector distances (Eff at SD), which are 9 and 12 cm distances from the detector's window.

Table 2. *The induced activity of the samples after the irradiation, where: eoi, a1d and a30d represent the end of irradiation, after 1 day, and after 30 days respectively.*

Sample ID	**Activity of sample (eoi) [MBq]**	**Activity of sample (a1d) [MBq]**	**Activity of sample (a30d) [MBq]**
Cd	2.1E-02	1.4E-02	2.5E-03
Sc	2.6E-04	2.6E-04	2.1E-04
Au-1	2.1E-01	1.6E-01	9.2E-05
Au-2	2.1E-01	1.6E-01	9.2E-05
Au-3	4.3E-02	3.2E-02	1.8E-05
Au-4	4.5E-02	3.4E-02	1.9E-05
Au-backup	4.5E-02	3.4E-02	1.9E-05
Au-6	1.5E-01	1.1E-01	6.7E-05
W	2.1E-01	1.0E-01	2.0E-03
In	3.3E-03	3.2E-03	2.2E-03
Ni	1.8E-03	1.5E-03	8.2E-04
Al	1.1E-03	1.4E-04	1.5E-18
Co	3.5E-04	1.9E-04	1.7E-04
Bi	1.2E-02	4.5E-03	5.2E-04
SUM	**9.6E-01**	**6.6E-01**	**8.6E-03**
Al Holder	2.6E-01	3.2E-02	3.4E-16
Total SUM	**1.2E+00**	**6.9E-01**	**8.6E-03**

Figure 4. *HPGe at n_TOF at CERN*

The planning of the measurements is done according to the decay parameters of the product nuclei as well as the expected activities. In any case, the measurement time for each sample is calculated considering peak area uncertainties of the order of 1-2%. Besides the consideration of the expected counting rates on the photo-peaks of interest, extensive GEANT4 simulations have taken place considering the total efficiency of the detectors as well as the full decay scheme of all the unstable product nuclei present in each sample. In this way, possible dead-time issues and considerable correction factors can be avoided. The measurement plan in its final state is given in Table 4.

Table 4. *Measurement plan*

Time [h]	***Sample ID***	***Reaction***	***Half Life***	***DAQ time [h]***	***Eff at SD[cm]***	***Eg [KeV]***	***Counts per Second***
Day 1							
10:00-11:00	W	^{186}W (n, g) ^{187}W	23.72 h	0.030	12	685.774	9.33E+01
11:00-12:00							
12:00-17:00	Ni	^{58}Ni (n, p) ^{58}Co	70.86 d	0.982	9	810.775	2.83E+00
		^{58}Ni (n, 2n) ^{57}Ni	35.60 h	3.547		1377.63	8.10E-01
17:00-18:00							
18:00-08:00	Al	^{27}Al (n, a) ^{24}Na	15 h	5.656	9	1368.633	5.58E-01
Day 2							
10:00-11:00	Cd	^{114}Cd (n, g) ^{115}Cd	53.46 h	0.359	9	527.9	7.76E+00
11:00-12:00							
12:00-17:00	Bi	^{209}Bi (n, 4n) ^{206}Bi	6.234 d	0.504	9	803.1	5.52E+00
		^{209}Bi (n, 5n) ^{205}Bi	15.31 d	4.453		1764.63	6.26E-01
Day 3							
10:00-14:00	Au-6	^{197}Au (n,2n) ^{196}Au	6.17d	3.7902	12	355.684	7.39E-01
14:00-15:00							
15:00-03:00	Au-3	^{197}Au (n, g) ^{198}Au	2.69 d	0.063	9	411.802	4.40E+01
		^{197}Au (n, 2n) ^{196}Au	6.17 d	9.491		355.684	2.99E-01
Day 4							
09:00-10:00							
10:00	Au-1	^{197}Au (n, g) ^{198}Au	2.69 d	0.026	12	411.802	1.09E+02
		^{197}Au (n, 2n) ^{196}Au	6.17 d	3.286		355.684	8.52E-01
		^{197}Au (n, 4n) ^{194}Au	38.2 h	94.524		328.455	6.15E-02

Day 7							
20:00-21:00							
21:00	Au-4	^{197}Au (n, g) ^{198}Au	2.69 d	0.169	9	411.802	1.65E+01
		^{197}Au (n, 2n) ^{196}Au	6.17 d	14.336		355.684	2.00E-01
Day 8							
12:00-13:00							
13:00-14:00	In	^{113}In (n, g)^{114m}In	49.51 d	0.666	9	190.29	4.17E+00
14:00-15:00							
15:00	Au-b	^{197}Au (n, g) ^{19}8Au	2.69 d	0.220	9	411.802	1.27E+01
		^{197}Au (n, 2n) ^{196}Au	6.17 d	16.219		355.684	1.78E-01
Day 9							
10:00-11:00							
11:00-19:00	Sc	^{45}Sc (n, g) ^{46}Sc	83.79 d	5.716	9	1120.545	4.86E-01
19:00-20:00							
20:00	Au-2	^{197}Au (n, g) ^{198}Au	2.69 d	0.092	12	411.802	3.01E+01
		^{197}Au (n, 2n) ^{196}Au	6.17 d	5.771		355.684	4.88E-01
Day 10							
09:00-10:00							
10:00	Co	^{59}Co (n, g) ^{60}Co	1925 d	13.967	9	1332.501	1.17E+02
		^{59}Co (n, 2n) ^{58}Co	70.86 d	19.597		810.775	1.42E-01
		^{59}Co (n, 3n) ^{57}Co	271.74d	36.296		122.0614	7.67E-02
Day 12							
11:00-12:00							
12:00	Au-1	^{197}Au (n, 3n) ^{195}Au	186.09d	127.524	12	99.85	2.20E-02
Day 19							
16:00-17:00							
17:00	Bi	^{209}Bi (n, 3n) ^{207}Bi	31.55y	163.911	9	569.702	1.70E-02
Day 29							
10:00							

CONCLUSIONS

After the second Long Shutdown period of CERN (LS2), a new experimental area – the NEAR Station - has already been established and is available for future experiments. In the present work, the preparation and planning of the first multi-foil activation measurement at the NEAR Station is presented in full detail. Different samples will be irradiated for almost 22 days. Afterward, the induced activities that correspond to the 17 reference reactions will be measured using a 27% relative efficiency HPGe Detector. The comparison of the experimental counting rates with expected ones allows for the direct benchmarking of the simulated neutron flux. Following the realization of this multifoil activation measurement, the demanding task of unfolding the complicated neutron beam energy spectrum is still in front of us.

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