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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Addendum to the ISOLDE and Neutron Time-of-Flight Committee

Neutron capture cross section measurements by the activation method at n_TOF/EAR2

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Abstract: Maxwellian-Averaged cross section (MACS) measurements play an important role in nuclear astrophysics, as they provide essential input to stellar models. One way to obtain MACS results is by performing an integral measurement with a Maxwellian-shaped incident beam. Such measurements were proposed in INTC-P-623, a feasibility study of shaping the n_TOF NEAR Station neutron beam into a Maxwellian-like distribution. This feasibility study can be complimented by measurements at EAR2. Even though EAR2 is not in itself preferable for MACS measurements, the accurate knowledge of its neutron flux can aid at cross-checking the shaping technique applied in NEAR through the comparison of experimental results with extensive simulations.

Requested protons: $10\text{x}10^{17}$ protons on target
Experimental Area: EAR2

1 Introduction

The present document is an addendum to proposal INTC-P-623 [1], which aimed at investigating the possibility of performing measurements of interest for nuclear astrophysics at the NEAR Station of n_TOF. In order to accurately reproduce elemental abundances, stellar models require input from nuclear physics, in the form of Maxwellian-averaged cross sections (MACS) with low uncertainties [2, 3]. Figure 1 shows an example of the uncertainty of various MACS results [4]. For many isotopes, the uncertainty is above 10% or even 20%.

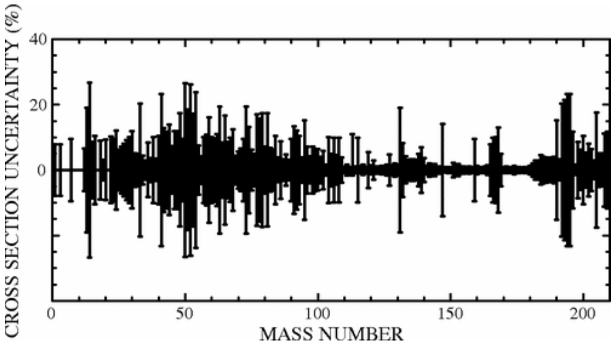

Figure 1: Cross section uncertainty as a function of the nulceus of interest mass number.

One way to obtain MACS results is by performing integral measurements with an incident beam of a Maxwellian energy distribution. The energy of the neutrons of the NEAR Station spans 11 orders of magnitude from thermal to GeV, thus, in order to aid in MACS measurements, it needs to be shaped accordingly. This can be achieved with the use of filters made from material with a high neutron capture cross section that can absorb the thermal and epithermal neutrons, thus removing them from the spectrum completely, as shown in Figure 2.

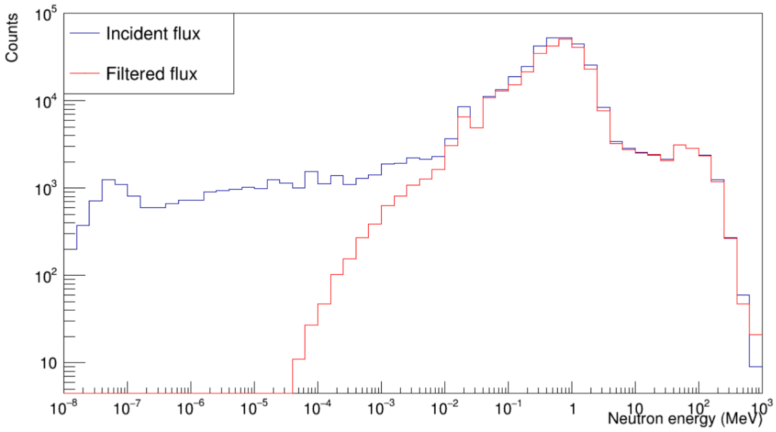

Figure 2: Simulation of the neutron energy distribution without and with the use of a $^{10}B_4C$ filter.

This behaviour is already being experimentally validated through the measurements of INTC-P-623. In those measurements, the effect that different thicknesses of a $^{10}B_4C$

filter have on the spectral-averaged cross section (SACS) of 5 neutron capture reactions is being studied. In order to accurately extract the SACS and compare with the predicted behaviour of the filter, the knowledge of the reaction cross section as well as the shape and absolute value of the neutron spectrum is crucial. The cross section as a function of neutron energy of the 5 chosen reactions has been measured at n_TOF via time-of-flight technique and is thus well-known. The unfiltered neutron energy distribution of the NEAR Station was investigated through several multifoil activation measurements, as proposed in [5], together with extensive FLUKA [6, 7] simulations. Some preliminary results of one of the multifoil activation measurements can be seen in 3, together with FLUKA simulation results for comparison. As can be seen, the simulated and unfolded flux are in agreement in the thermal, epithermal and keV region while some disagreement is observed in the high energy region. The binning of the experimental results is constrained by the number and type of reactions chosen for the multifoil activation and thus at this stage cannot be any finer. It can be used however to validate the simulations in terms of absolute value.

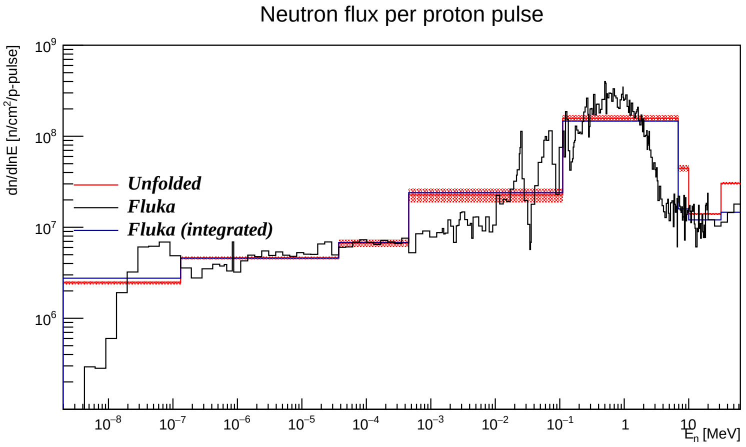

Figure 3: Current status of the NEAR Station neutron energy distribution unfolding. In red, the experimentally unfolded values. In black, the results of FLUKA simulations and in blue the FLUKA results but integrated in the same binning as the experimental results.

In order to avoid possible systematic uncertainties caused by a possible incomplete knowledge of the NEAR neutron energy distribution, in each irradiation a gold foil was always irradiated together with each sample. In this way, the ratio of SACS (sample/Au) can be compared with the ratio of MACS (sample/Au) of the temperature corresponding to the thickness of the used filter. The agreement of those two ratios can provide an indication for the agreement of the shape of the NEAR flux with the ideal Maxwellian shape. Some preliminary results on this are summarised in Table 1. All MACS were calculated with the available online tool of Brookhaven National Laboratory's Nuclear Data Center [8, 9, 10] and the temperatures were selected through fitting the simulated flux with a Maxwellian distribution.

$^{10}B_4C$ thickness [mm]	$SACS_{Ge}/SACS_{Au}$	$MACS_{Ge}/MACS_{Au}$	Ratio SACS/MACS
5	0.017	0.025	0.68
10	0.020	0.037	0.54
15	0.022	0.022	1.01
20	0.024	0.027	0.88

Table 1: Ratio of spectral- and Maxwellian-averaged cross section of ^{76}Ge to ^{197}Au. The ratio of the two, SACS/MACS, is also presented. The latter is an indication of the filtered flux shape: The closer this ratio is to 1, the closer the shape of the filtered flux is to the ideal Maxwellian shape.

2 Irradiation at EAR2

After the various upgrades of n_TOF during LS2, EAR2 was commissioned and its characteristics were investigated with different detection setups, as proposed in [11]. Its neutron flux was measured with statistical uncertainty of $\sim 3\%$ in the thermal and epithermal energy regions and is given with a very fine energy binning. Even though EAR2 is not in itself perfectly suitable for integral MACS measurements, the excellent knowledge of its neutron beam energy distribution allows for benchmarking and better exploring the details of the shaping technique through comparing simulations with measurements performed in EAR2. For this reason we are proposing the following measurements, complimentary to the ones of INTC-P-623, to be performed in EAR2:

Reaction	Filter [mm]	$T_{1/2}$ [d]	Irradiation time [d]	Expected activity [Bq]
^{197}Au(n,γ)^{198}Au	10	2.69	1	1.5
^{197}Au(n,γ)^{198}Au	20	2.69	1	1.0
^{140}Ce(n,γ)^{141}Ce	20	32.5	8	0.4

Table 2: Reactions proposed to be studied in EAR2, complimentary to INTC-P-623 [1], as a cross-check of the filtering method. The irradiation time indicated above is the minimum time required to achieve a statistical uncertainty of $\sim 2\%$ within a reasonable measuring time.

The experimental setup will comprise the same samples and filters as INTC-P-623. The filters consist of different $^{10}B_4C$ disks that can be combined to achieve various final filter thicknesses. The characteristics of the samples are summarised in Table 3. Each sample will be accompanied by a gold reference sample as well.

Sample	Material	Mass [g]	Thickness [mm]	Form
Ce2	CeO_2	0.20247	2.2	Pellet
Au	Au	0.00855	0.025	Metallic foil

Table 3: Characteristics of the samples. All of them have a diameter of 5mm.

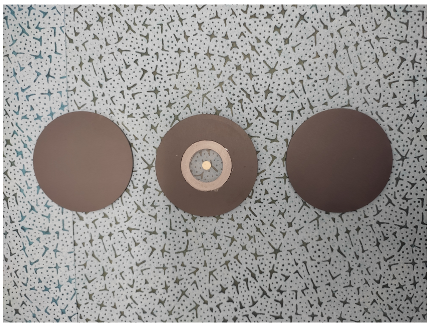

Figure 4: Two $^{10}B_4C$ disks together with a sample inserted in a $^{10}B_4C$ ring

Summary of requested protons: 10x10^{17} protons on target in EAR2

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

Please describe here below the main parts of your experimental set-up:

Part of the experiment	Design and manufacturing
If relevant, write here the name of the fixed installation you will be using GEAR-HPGe	☒ To be used without any modification ☐ To be modified
If relevant, describe here the name of the flexible/transported equipment you will bring to CERN from your Institute N/A	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
N/A	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[insert lines if needed]	

HAZARDS GENERATED BY THE EXPERIMENT

Additional hazard from flexible or transported equipment to the CERN site:

Domain	Hazards/Hazardous Activities		Description
Mechanical Safety	Pressure	☐	[pressure] [bar], [volume][l]
	Vacuum	☐	
	Machine tools	☐	
	Mechanical energy (moving parts)	☐	
	Hot/Cold surfaces	☐	
Cryogenic Safety	Cryogenic fluid	☐	[fluid] [m3]
Electrical Safety	Electrical equipment and installations	☐	[voltage] [V], [current] [A]
	High Voltage equipment	☐	[voltage] [V]
Chemical Safety	CMR (carcinogens, mutagens and toxic to reproduction)	☐	[fluid], [quantity]
	Toxic/Irritant	☐	[fluid], [quantity]
	Corrosive	☐	[fluid], [quantity]
	Oxidizing	☐	[fluid], [quantity]
	Flammable/Potentially explosive atmospheres	☐	[fluid], [quantity]
	Dangerous for the environment	☐	[fluid], [quantity]
Non-ionizing radiation Safety	Laser	☐	[laser], [class]
	UV light	☐	
	Magnetic field	☐	[magnetic field] [T]

Workplace	Excessive noise	☐	
	Working outside normal working hours	☐	
	Working at height (climbing platforms, etc.)	☐	
	Outdoor activities	☐	
Fire Safety	Ignition sources	☐	
	Combustible Materials	☐	
	Hot Work (e.g. welding, grinding)	☐	
Other hazards			