NEUTRONIC PERFORMANCE OF THE MEGAPIE TARGET

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MEGAPIE, the first liquid metal target irradiated by a proton beam at the MW power level, was successfully operated in 2006. A continuous beam of 575 MeV protons with a current up to 1.35 mA irradiated the liquid lead-bismuth target placed in the SINQ target location at PSI (Switzerland) for a period of four months.

The neutronic performance of the target was studied with the goals of validating the Monte Carlo codes used in the design of the target; additionally, the performance was compared with the solid Pb targets used before and after the MEGAPIE experiment. Absolute thermal and epithermal neutron fluxes were measured at various beam lines at the end of the SINQ target block (about 6-7 m from the centre of the target) and at a measuring station close to the center of the target.

The results show a clear increase of the neutron flux delivered to the users with respect to the solid target irradiated before MEGAPIE, between a factor 1.6 and 1.8, depending on the beam lines. The agreement between absolute flux values with the calculations is good for most of the measurements, indicating that the fluxes with the MEGAPIE target model are correctly calculated. A preliminary comparison with the latest SINQ solid target, operated in 2007 after MEGAPIE, was also made.

The excellent performance of a compact molten metal target is clearly an asset in view of future target development, for applications in ADS or for neutron facilities.

I. INTRODUCTION

The MEGAwatt PIlot Experiment (MEGAPIE) project[1] was started in 2000 to design, build and operate a liquid metal spallation neutron target of 1 MW beam power. The project is an important step in the roadmap towards the demonstration of the Acceleration Driven System (ADS) concept[2] and high power molten metal targets in general.

In the MEGAPIE target a loop of about 82 liters of lead-bismuth eutectic (LBE) circulates enclosed by a steel structure. The target is about 5 m long and the LBE loop circulates by means of a main electromagnetic pump, while a bypass pump is used for a secondary loop to cool the window. The target was inserted in the SINQ block replacing the previous solid targets[3], and was operated during 4 months in 2006.

Prior to operation, several R&D task groups worked on the design of the target. Among them, the so-called "X9" task group worked on the neutronic and nuclear assessment. Several topical issues, among which the neutronic performance, power deposition, radiation damage, dose rates, gas production and activation, were studied.

The study of the neutronic performance of MEGAPIE is important for ADS applications, and for SINQ users. In the framework of accelerator driven systems, neutronic aspects are of great interest to get a deep knowledge of the target; for this purpose it is important to study the fast neutron flux in the vicinity of the spallation region, where also transmutation rates can be studied[4], even though it is partially moderated by the surrounding D_2O tank, and therefore not fully representative of an ADS spectrum; another important aspect of an experiment such as MEGAPIE is in the measurement of the gas produced and released by the target during operation.

The neutronic performance of MEGAPIE is also of great interest for SINQ users. In fact, while the main motivation for the MEGAPIE experiment was related to ADS applications, the possibility to use a liquid target for routine production of neutrons in a research facility needs to be considered, in view of its optimized neutronic performance and the potentially higher current densities that can be accepted. For this purpose it is important to compare the neutronic performance of a liquid target with the standard solid targets used in SINQ. Neutronic aspects were investigated during the design phase of MEGAPIE[5]. Besides measuring the neutron flux increase using a liquid metal target, it is important to study the energy spectrum to see for instance if the fast neutron flux increases by the same amount, or if the background is different with a liquid metal target. Since the liquid and the solid target differ in the fact that the neutrons are already partially moderated in a SINQ type solid target (because the target rods are cooled with circulating heavy water), in principle differences in the spectral distributions can be expected.

Neutronic measurements must be accompanied by Monte Carlo calculations. In fact, Monte Carlo codes were the main tools used during the design phase for the neutronic and nuclear assessment of the MEGAPIE target. Important quantities such as neutron fluxes, power deposition in the target, shielding, dose rates, activation, gas production, and radiation damage, were calculated and the effects of the target design on the nuclear performance were evaluated. Clearly the input of the neutronic calculations is essential for instance for the design of the target beam window, for the target shielding, and for the handling procedure of the target after irradiation.

As a reference for the calculated target performance, in Fig. 1 the MCNPX results for the MEGAPIE target inserted in the SINQ heavy water tank, without the beam lines, is shown. The figure gives the radial distribution of the integrated flux below 1 eV.

This paper concentrates in the measurement and calculation of the neutronic performance of the MEGAPIE target.

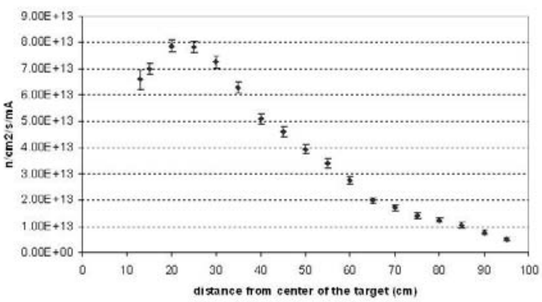

Fig. 1. Calculated radial distribution of the unperturbed neutron flux in MEGAPIE.

II. MEASUREMENTS

Before the start of the irradiation of MEGAPIE, a measurement program was set up by the neutronic and nuclear assessment task group, which included the measurement of the neutron flux at several positions of the facility. The program included the flux measurement in close proximity of the neutron production region, where a flux of the order of 10^{14} n/cm^2/s/mA is expected[4], then additional measurements at various points in the facility, with flux figures varying from 10^{12} n/cm^2/s/mA to 10^8 n/cm^2/s/mA. A complete characterization of the neutronic performance of the SINQ facility with the MEGAPIE target, spanning six orders of magnitude, is therefore expected. This set of data is of great value for the benchmarking of the Monte Carlo codes.

Measurements using the activation foil technique were performed at several points of the facility, including positions where measurements done in previous years existed, thus allowing the determination of the neutronic performance of MEGAPIE compared to the previous solid target. These measurements and relative calculations are the main subject of this paper.

Activation foils were irradiated at three beam lines of the SINQ facility: ICON, NEUTRA and EIGER (see Fig. 1); additionally, measurements were performed at the NAA irradiation station located inside the moderator tank. The measurement positions are shown in Fig. 2. Of the three beam lines, NEUTRA and EIGER are thermal neutrons lines, while ICON is a beam line for cold neutrons from a D_2 moderator placed inside the heavy water tank. The integral fluxes vary from about 10^{13} n/cm^2/s/mA at the NAA to about 10^8 n/cm^2/s/mA.

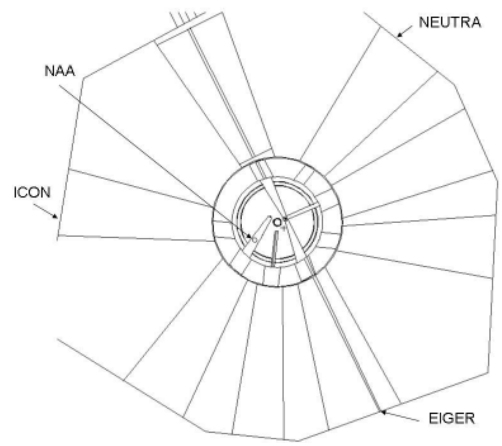

Fig. 2. Top view of the MCNPX model of the SINQ facility with the MEGAPIE target.

II.A. NAA

The Neutron Activation Analysis (NAA) station is an irradiation station located inside the heavy water tank, at about 80 cm from the center of the SINQ target. At the NAA station, samples are placed inside polyethylene capsules, and sent to two irradiation positions by means of a pneumatic system. Gold and cobalt foils were irradiated to measure the thermal neutron flux. Some measurements were performed with the samples placed inside Cd capsules for thermal neutron absorption and correction for the activation due to non thermal neutrons. A coarse estimate of the epithermal flux is given by the Au and Co foils activated inside the Cd. The samples where thin enough that contributions from self shielding were negligible.

Additionally, a set of threshold detectors was irradiated to measure reaction rates induced by neutrons with energy greater than 1 MeV. Measurements were performed in 2006 (MEGAPIE target) and 2007 (SINQ solid target). In 2006 foils of Al, Ti, Mn, Fe, Ni, and Cu were used. In 2007 the foils were of Al, Ti, Mn, Fe, Co and Cu. Results from previous measurements existed and were compared.

After irradiation, the activities in the foils were measured using an HPGe detector previously calibrated. The analysis of the γ spectra was performed using the GENIE software[6]. For the threshold detectors, irradiation times up to 1 hour were applied, with proton beam currents of about 1 mA.

II.B. Beam lines

Gold foils were placed at the exit of the ICON, NEUTRA and EIGER beam lines (see Fig. 2). In addition, at least one of the gold foils at ICON and EIGER was covered with Cd in order to correct for the epithermal neutron flux. ICON is one of the cold neutron beam lines with direct view to the cold source. NEUTRA and EIGER are thermal beam lines. The EIGER beam line has two special characteristics. First, the beam line looks on the water scatterer which is close to the target; second, the collimation is coated by supermirrors. To observe the expected vertical neutron flux distribution, several gold foils were positioned along the vertical beam center. The diameter of each foil was 10 mm. In 2005 and 2006 only five measurement positions were used. To get a more detailed vertical flux distribution the number of positions was increased to 11 in 2007. The foils were distributed over height of 13 cm. Furthermore, the positioning was done with a previous beam image measurement using image plates. In this way the gold foils could be perfectly positioned. The comparison of absolute neutron fluxes for simulated and measured values is shown in Fig. 3. The agreement looks very well for the middle part of the profile (distribution). At the edges we can observe small differences which can be explained by the non-perfect model (no vertical flux distribution was considered for the water scatterer) and the use of a limited number of data points in the simulation. In fact each simulated data point represents exactly the size of a gold foil. To compare the beam profile more precisely, a second simulation was done where the number of data points was increased to 200. The results are shown in Fig. 4. Now the simulated and measured vertical beam profile are showing nearly a perfect agreement. Only the effect of the inhomogeneous flux distribution at the water scatterer surface results in the small differences on right side of the beam profile.

II.C. Systematic uncertainties

In order to know the performance of the MEGAPIE target we are interested in the systematic uncertainties of the flux measurements. Due to the well known gold and cobalt thermal capture cross sections, and to the accurate measurements of the masses of the foils, the major source of uncertainty comes from the positioning of the samples. The most precise indication on the systematic uncertainties comes from the measurements at NAA and EIGER. At NAA a precision in the measurements better than 5 % was found in previous investigations. Also at EIGER the measurements have relatively low systematic uncertainty, thanks to the accurate profile measurements of the integrated fluxes at the beam exits described above. A systematic uncertainty better than 5% for the 2007 measurements, and of about 7 % for the 2006 measurement was estimated. For ICON and NEUTRA, beam profile measurements were not so detailed, and we conservatively give an uncertainty of 10 % to these measurements.

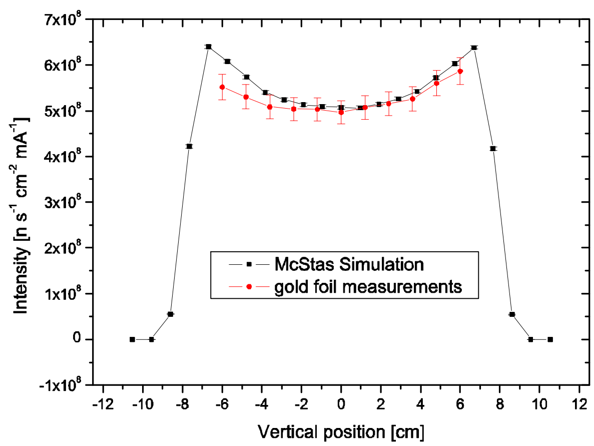

Fig. 3. Vertical distribution of the absolute thermal neutron flux at the guide exit of the EIGER beam line. Comparison between gold foil measurements and McStas simulation.

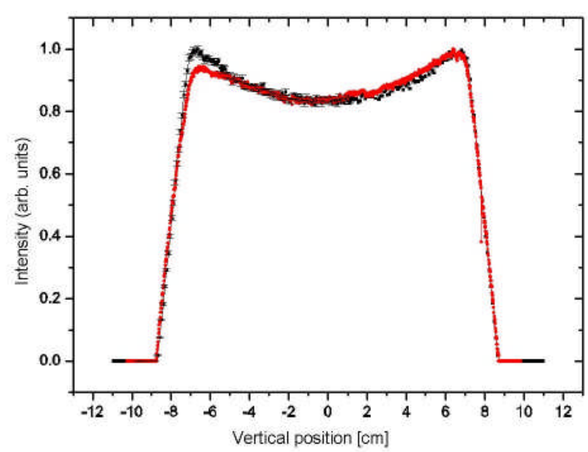

Fig. 4. Vertical distribution of the thermal neutron flux on a relative scale taken at the guide exit of the EIGER beam line. Comparison between Image Plate measurement and McStas simulation.

II.D. Thermal neutron fluxes

In order to extract the absolute thermal and epithermal neutron fluxes, thin gold foils were irradiated without and with cadmium covers, respectively.

Time-of-flight measurements as well as MCNPX calculations indicate that the thermal peak values are higher than the nominal value of 0.025 eV for the thermal beam lines. For the ICON cold neutron beam line, the peak flux is of course at a lower energy, due to the presence of the D_2 moderator. Therefore effective, averaged between 0 and 1 eV, neutron capture cross sections of gold and cobalt were calculated according to the actual flux distributions, see eq. 1:

$$\sigma_{EFF} = \frac{\int_0^{1eV} \phi(E)\sigma(E)dE}{\int_0^{1eV} \phi(E)dE} \qquad (1)$$

As shown in Table I, the effective thermal cross sections differ significantly from the nominal gold thermal neutron capture cross section of 98.7 barns. In the table calculated cross sections for MEGAPIE are shown. Values for target 6 and target 7 are very close. In the case of the ICON and NEUTRA beam lines experimental time-of-flight measurements of the neutron spectra were available. In this case the difference with the calculated values is at most of 7%. In these cases the experimental values were used in the analysis.

TABLE I. Effective thermal cross sections.

	Exp. [barn]	MEGAPIE [barn]
ICON	158.3 (ref. 7)	170
NEUTRA	80 (ref. 8)	82.6
EIGER		82.8
NAA		86.1

II.E. Epithermal neutron fluxes

Gold and cobalt foil measurements were performed with and without Cd layers. From this measurement one can obtain the pure thermal flux, but it is also possible to have an indication of the epithermal flux. In principle for an accurate measurement of the flux in the epithermal region (5 eV with a Au foil, 132 eV with a Co foil) one should measure with the double foil technique. Using a single foil, we can only have an approximate estimate of the epithermal flux, which is valid especially for gold, since the resonance integral neutron capture cross sections is practically equal to the capture cross section of the resonance at 4.9 eV. A value for the epithermal neutron flux was therefore estimated from these measurements and compared with the calculated values.

II.F. Fast neutrons

Reaction rates were measured for several foils with threshold reactions from 1 MeV up. As the cross sections for the threshold reactions span a wide energy range in the MeV region, the absolute fluxes can be determined using an unfolding program. Nevertheless, even without unfolding the measured reaction rates, at this point we can determine the relative fast neutron flux of MEGAPIE compared to the solid targets which gives an indication of the fast background to the SINQ users.

III. SIMULATIONS

The neutron flux calculations were performed using MCNPX 2.5.0[9]. A detailed model prepared within the MEGAPIE collaboration[10] was used. Three separate models of the SINQ facility were prepared, where the only differences consisted in the spallation targets: an accurate geometrical description of the latest two solid targets and of MEGAPIE was performed; the surrounding SINQ facility was the same in the three models.

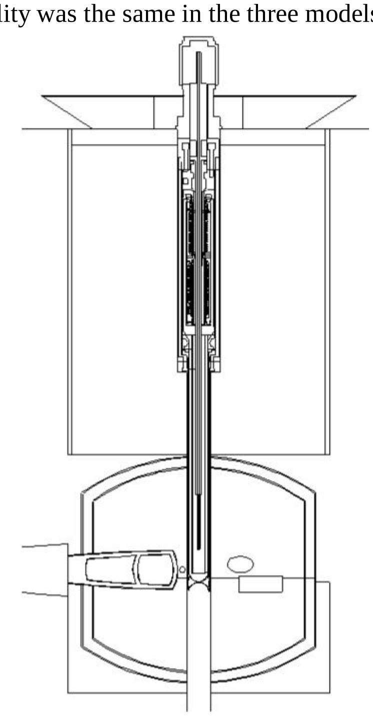

Fig. 5. Side view of the MCNPX model of the MEGAPIE target inserted in the SINQ facility.

As the absolute neutron fluxes need to be calculated at the beam lines, which are up to about 7 m away from the target center, the entire SINQ target block was modeled, and the beam lines collimators were included in an attempt to calculate precisely the fluxes. A view of the geometry of the model with the MEGAPIE target is represented in Fig. 5.

III.A. MEGAPIE

In the case of MEGAPIE, the bottom of the target, where the spallation reactions take place, contains several structural components besides the LBE. Details of the loop, also above the spallation region were modeled with care, since this can be of great help for comparison with delayed neutrons experiments, and for activation calculations.

III.B. Solid targets

For the simulations of the solid targets used in 2004-2005 (target 6) and in 2007 (target 7), the same model was used, whereas the solid rod targets replaced MEGAPIE. Two views of the geometry are shown in Figs. 6 and 7. The target 6 consisted of a bundle of rods arranged in layers of 9 and 10 rods each, for a total of 37 rows and 351 rods. Each rod consists of a cylinder with radius of 0.54 cm and 13.6 cm length. There are different types of rods: 1) the majority consists of Pb rods inside steel 316L cladding, the volume of the cladding being filled to 90% with Pb; 2) the lowest row of 9 rods consists of AlMg3 cylinders which are open (therefore allowing the D_2O to circulate), for cooling purpose during operation; 3) for the rods at the sides of the bundle zircaloy replaces the steel; 4) several rods filled with specimens for the STIP[11,12] program (mostly steel specimens) occupy some of the central positions in the target.

The target 7, which was inserted in the SINQ facility after the end of the MEGAPIE irradiation program, is very similar to target 6. The difference consists in the cladding (only zircaloy is used) and in a different arrangement of the STIP samples in the target.

III.C. Calculation parameters and procedure

The material definition is very important for flux calculations, as the presence of neutron capturing materials (such as the steel, or impurities in the LBE) will affect the target performance. Precise compositions for the steels (T91 and 316L), and for the AlMg3 was applied. A chemical analysis of a sample of LBE (from the stock that was used in MEGAPIE) was performed, and a list of impurities extracted. We note however that the level of concentration of such impurities (at the ppm level) does not affect significantly the neutronic performance of MEGAPIE.

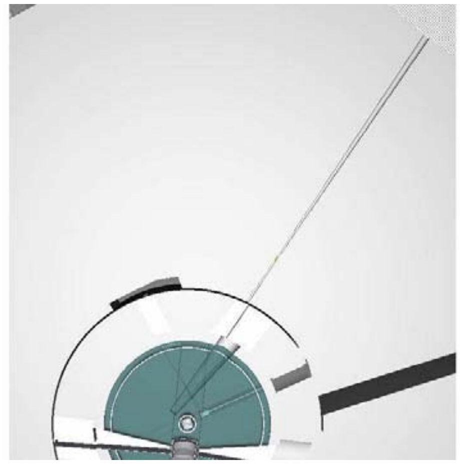

Fig. 6. Horizontal cut of the MCNPX model of the SINQ facility, showing also the collimation system of the NEUTRA beam line.

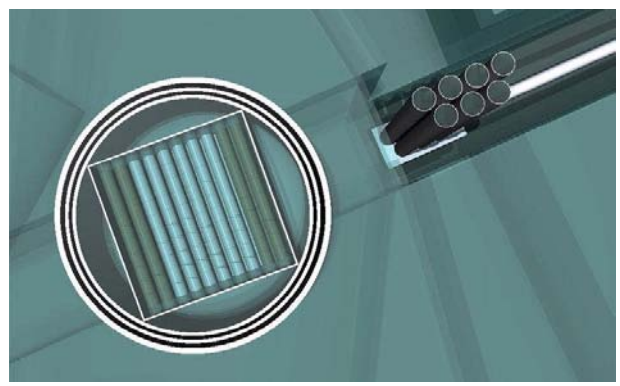

Fig. 7. Horizontal cut of the MCNPX model of the SINQ solid target with the water scatterer.

The beam profile is of lower importance for the results presented in this work, while it is more relevant for the flux in proximity of the proton interaction zone. Nevertheless, in the frame of the X9 activities, a precise modeling of the calculated 2-dimensional beam profile[13] was implemented in the MCNPX input file.

MCNPX calculations were performed for the three targets and at least 10^6 proton histories were run for each case. Protons of 575 MeV energy were generated.

Neutron cross sections up to 20 MeV were used; above that value models were applied in MCNPX. For the flux calculations, f5 tallies were used, except for the case of NAA where both f4 and f5 tallies were computed, verifying the agreement (better than 1 %) between the two calculations. A weight-window mesh was created on top the geometry to increase the statistics at the beam lines. In the case of NAA, a calculation without weight window, performed in the MEGAPIE case, showed an agreement at the level of 1% between calculations with and without weight window.

IV. RESULTS

IV.A. Thermal neutron fluxes

Preliminary results from integrated thermal neutron measurements are shown in Table II for the target 6, MEGAPIE and target 7, respectively. MCNPX values are the integrated fluxes up to 1 eV neutron energy, while experimental values are from the measurements where the contribution from epithermal neutrons is subtracted, and the flux is obtained by dividing for the effective cross section between 0 and 1 eV. These values are therefore directly comparable.

TABLE II. Preliminary experimental and calculated thermal flux results.

	Experimental [n/cm^{2}s/mA]	MCNPX [n/cm^{2}s/mA]
SINQ target 6		
ICON	3.80 10^8 (10)	5.29 10^8 (0.80)
NEUTRA	2.59 10^7 (10)	2.76 10^7 (0.89)
EIGER	6.64 10^8 (7)	9.46 10^8 (0.50)
NAA	5.80 10^{12} (5)	7.02 10^{12} (0.74)
MEGAPIE		
ICON	6.89 10^8 (10)	8.53 10^8 (0.61)
NEUTRA	4.80 10^7 (10)	4.34 10^7 (0.33)
EIGER	1.05 10^9 (7)	1.64 10^9 (0.35)
NAA	1.04 10^{13} (5)	1.21 10^{13} (0.27)
SINQ target 7		
ICON	4.23 10^8 (10)	5.78 10^8 (0.69)
NEUTRA	2.83 10^7 (10)	3.15 10^7 (1.1)
EIGER	6.91 10^8 (5)	1.01 10^9 (0.62)
NAA	6.62 10^{12} (5)	7.58 10^{12} (0.94)

The ratios between the fluxes of MEGAPIE and the solid targets are shown in figures 8 and 9. On the average MEGAPIE has a neutronic performance higher than target 6 of a factor 1.76 ± 0.11, and of a factor of 1.60 ± 0.09 with respect to target 7.

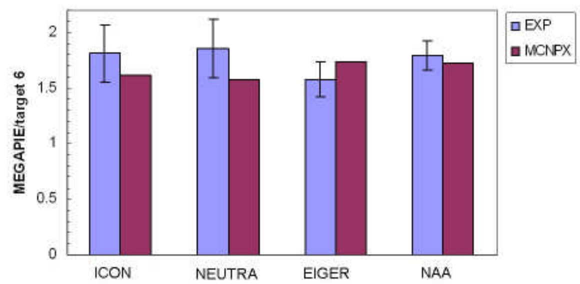

Fig. 8. Comparison between measured and calculated MEGAPIE target performance relative to target 6.

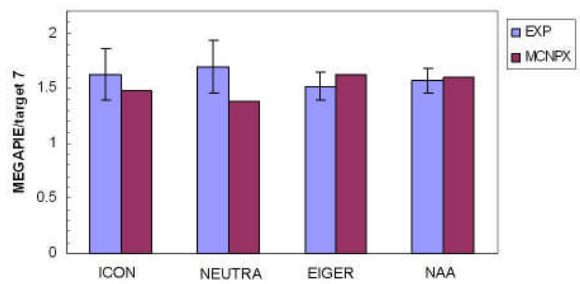

Fig. 9. Comparison between measured and calculated MEGAPIE target performance relative to target 7.

IV.B. Epithermal neutron component

Indicative values on the epithermal fluxes can be extracted from the activation measurements where the gold or cobalt foils were enclosed in a Cd capsule. Gold has a strong resonance at 4.9 eV with a capture area of 1551 barn, corresponding to 99.7 % of the resonance integral. Also in the case of cobalt the resonance integral is strongly dominated by a single resonance at 132 eV. It is however not possible to obtain a pure flux measurement at these resonances without using the double foil technique, and therefore these values are only indicative. We discuss here only the relative increase of the epithermal component with the MEGAPIE target.

The epithermal fluxes constitute some percent of the total fluxes. With the MEGAPIE target an increase of a factor of 2.5 is observed with respect to the 2005 solid target, and a factor 2.6 with respect to the 2007 solid target. Calculations indicate an increase of factors 2.1 and 2.0, respectively. However, the uncertainty in the epithermal flux is larger than the one in the thermal flux.

IV.C. Fast neutron component

For the fast neutrons, good indications are obtained by reaction rate measurements with threshold detectors measured at NAA. Some relevant results are reported in

Table III. Some interesting information can be extracted from these data. First of all, we can compare with the reaction rates measured with the different targets to have an idea of the changes of the fast neutron flux at the NAA position.

TABLE III. Preliminary measured reaction rates per atom [s^{-1}] for 2001 target[15], MEGAPIE and SINQ target 7. Values in brackets : % uncertainties.

nuclide	2001 target	MEGAPIE	target 7
Mn sample			
^{52}Mn	1.85 10^{-16} (2.4)	2.02 10^{-16} (0.4)	1.99 10^{-16} (6.9)
^{54}Mn	5.51 10^{-15} (0.8)	6.86 10^{-15} (0.3)	6.03 10^{-15} (10)
^{51}Cr	4.89 10^{-16} (2.3)	5.03 10^{-16} (0.7)	4.98 10^{-16} (2.9)
Ni sample			
^{48}V	2.53 10^{-17} (4.2)	2.64 10^{-17} (2.9)	2.62 10^{-17} (5.8)
^{51}Cr	1.84 10^{-16} (11)	1.37 10^{-16} (4.0)	2.01 10^{-16} (2.5)
^{52}Mn	1.16 10^{-16} (1.5)	1.19 10^{-16} (1.1)	1.24 10^{-16} (8.2)
^{54}Mn	3.89 10^{-16} (5.2)	4.66 10^{-16} (3.6)	4.39 10^{-16} (10)
^{56}Co	1.03 10^{-15} (1.9)	1.17 10^{-15} (0.9)	1.33 10^{-15} (6.1)
^{57}Co	4.73 10^{-15} (13)	4.91 10^{-15} (1.6)	
^{58}Co	5.20 10^{-15} (1.3)	7.09 10^{-15} (0.4)	6.34 10^{-15} (10)
^{56}Ni	2.09 10^{-17} (7.6)	2.22 10^{-17} (1.0)	2.67 10^{-17} (25)
Al sample			
^{22}Na	1.53 10^{-16} (1.2)	1.98 10^{-16} (2.1)	
^{24}Na	8.46 10^{-16} (2.5)	7.7 10^{-16} (0.2)	7.95 10^{-16} (1.0)
Ti sample			
^{44}Sc	1.24 10^{-16} (0.5)	1.59 10^{-16} (0.9)	1.15 10^{-17} (4.0)
^{44m}Sc	1.23 10^{-16} (1.0)	1.44 10^{-16} (0.5)	1.21 10^{-16} (4.1)
^{46}Sc	1.41 10^{-15} (2.0)	1.99 10^{-15} (0.6)	2.26 10^{-15} (10)
^{47}Sc	1.70 10^{-15} (1.0)	2.19 10^{-15} (0.1)	1.72 10^{-15} (6.1)
^{48}Sc	4.36 10^{-16} (1.9)	6.29 10^{-16} (0.3)	4.86 10^{-16} (6.8)
Cu sample			
^{44}Sc	1.75 10^{-19} (-)	2.03 10^{-19} (4.5)	
^{44m}Sc	9.69 10^{-20} (-)	7.59 10^{-20} (3.8)	
^{51}Cr	1.20 10^{-17} (2.1)	1.49 10^{-17} (1.5)	1.24 10^{-17} (15)
^{52}Mn	5.25 10^{-18} (1.2)	4.80 10^{-18} (0.5)	6.03 10^{-18} (8.6)
^{54}Mn	5.08 10^{-17} (1.2)	5.39 10^{-17} (1.2)	6.22 10^{-17} (11)
^{57}Co	2.20 10^{-16} (0.3)	2.29 10^{-16} (0.3)	
^{58}Co	4.82 10^{-16} (0.6)	5.84 10^{-16} (0.2)	5.42 10^{-16} (10)
^{60}Co	4.37 10^{-16} (1.3)	5.95 10^{-16} (0.8)	5.50 10^{-16} (5.4)
^{59}Fe	3.27 10^{-17} (0.5)	4.08 10^{-17} (0.7)	
Fe sample			
^{47}Sc	7.90 10^{-18} (5.3)	8.26 10^{-18} (1.9)	9.60 10^{-18} (7.7)
^{51}Cr	5.22 10^{-16} (1.1)	4.26 10^{-16} (1.8)	6.22 10^{-16} (2.7)
^{52}Mn	1.53 10^{-16} (4.0)	1.03 10^{-16} (0.6)	1.78 10^{-16} (8.1)
^{54}Mn	2.01 10^{-15} (1.7)	1.58 10^{-15} (1.4)	2.39 10^{-15} (0.8)

From the results in Table III we see that the reaction rates taken with the different targets are on average very close. This seems to indicate that the fast neutron flux with MEGAPIE is about the same as with the solid targets, that is, the fast flux does not increase as the thermal and epithermal one. For instance, the average ratio between reaction rates measured with MEGAPIE and the 2001 solid target is 1.13. Calculations give a factor of 1.1. This interesting result could be explained by the different structures of the two spallation targets, and to the influence of the heavy water inside the solid targets on the fast spectrum at the measured position. However, a confirmation of these results would be strengthened by an absolute measurement of the fast flux, which is possible by use of an unfolding program. We plan to perform this analysis in the future.

V. CONCLUSIONS

The neutronic performance studies made during the design work showed the improvement of the MEGAPIE target with respect to the conventional solid target used at SINQ.

Integrated thermal neutron fluxes ($0 < E < 0.995$ eV) were measured at four positions of the SINQ facility. The increase in the thermal flux is of a factor 1.76 ± 0.11 compared to target 6 (2004-2005), and of a factor 1.60 ± 0.09 compared to target 7 (2007). The experimental results agree well on average with the calculations, even though some fluctuations are observed for the individual points, in particular for the NEUTRA beam line, where the calculated MEGAPIE performance is much lower than the measured one. The reason for this discrepancy is still not clear and could be due to not perfect modeling.

Overall, the present set of data and calculations provides a good understanding of the neutronic performance of the SINQ facility with different targets. Absolute thermal and epithermal fluxes, ranging from 10^{13} n/cm/s/mA to 10^{7} n/cm/s/mA, have been measured. The Monte Carlo model of the facility, with the different targets, has proven to be successful in correctly reproducing the experimental results, with discrepancy of at most 50% for the thermal component at the farthest measuring positions, and of a factor of 2 for the epithermal component. Work is in progress to try to improve the absolute thermal flux results. These results are very promising also in view of future studies of the facility and of future target developments.

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