Neutron Flux Characterization of MEGAPIE Target

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Abstract

The neutronic performances of the MEGAPIE target will be studied using fission micro-chambers specially designed to stand the severe irradiation conditions of flux and temperature. The absolute neutron flux will be monitor on-line at different positions inside the target in order to study its spatial and temporal variations. Together with the flux characterisation, actinide incineration potential of such target will be study through ^{241}Am and ^{237}Np isotopes. Prototype fission detectors and electronics have been successfully tested during the past three years at the High Flux Reactor of Laue Langevin Institute. The results of these tests are presented.

Keywords: fission chambers, neutron flux, neutron sources, spallation.
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1. Introduction

The MEGAPIE (MEGAwatt PIlot Experiment) project [1] aims to build and operate the first 1 MW liquid Pb-Bi spallation target as a key experiment on the road to Accelerator Driven Systems. Irradiation will start in 2006 for a foreseen period of 6-9 months at the SINQ

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installation of the Paul Scherrer Institut (PSI Zurich). The average proton energy will reach 575 MeV, for a beam intensity of 1.4 mA. During operation and after post-irradiation analysis, MEGAPIE project will provide the scientific community with unique data on the behavior (mechanical constraints, beam window corrosion, neutronic performances…) of a liquid target under realistic and long term irradiation conditions.

For this purpose, and in the framework of the Mini-INCA project [2,3], a complex detector made of 8 fission “micro”-chambers[1] is on the way to be manufactured. The chambers will be implanted inside the central rod of the MEGAPIE target. They will monitor on-line the spatial and temporal neutron flux variations as well as the evolution of the thermal versus epithermal components. The whole information gathered will offer integral constraints for the neutron generation and transport codes. In addition, measurements of the time-integrated fission rate (incineration potential) for ^{237}Np and ^{241}Am will be achieved in a 40% thermal flux. These data will complete integral incineration measurements already done or to be performed in the framework of the MINI-INCA project in a more thermal neutron flux at ILL [4].

2. Description of the Neutron Flux Detector

The implantation of the detectors inside the thinnest part of the central rod is shown on Fig. 1. This part is the closest from the neutron production area and has a length of 497 cm for a diameter of only 1.3 cm Due to the small place available, the choice of 4.7 mm in diameter fission chambers has been done. These chambers, already used successfully in high neutron fluxes at ILL (Grenoble) [5], have had to be adapted for the MEGAPIE severe irradiation conditions of electromagnetic and radiation perturbations and high temperatures frequently varying.

Two 40 and 150 μg ^{235}U deposit chambers will be placed at 47 and 71 cm, respectively, from the window to monitor the thermal component of the flux. A specific 150 μg ^{235}U deposit chamber shielded with 200 μm of Gadolinium will be placed at the closest position from the target. This chamber will be dedicated to the measurement of the non-thermal component of the flux. All ^{235}U deposit chambers will be accompanied with no-deposit chambers to perform an optimal background subtraction. Finally, 2 chambers with ^{241}Am and ^{237}Np deposits will provide interesting information on the incineration of these actinides in the MEGAPIE neutron flux. To complete the spectral analysis of the flux, 9 threshold reaction flux monitors will be irradiated together with the fission chambers. They are made of several ultra pure metals. Their characteristics are presented in table 1.

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[1] CFUT/C3 developed by PHOTONIS company

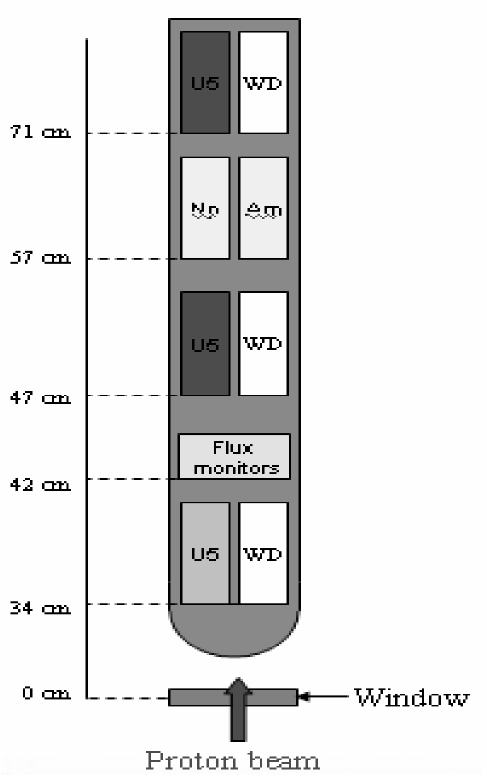


Fig. 1. Location of the fission chambers inside the central rod (WD = without deposit, U5 = Uranium deposit chamber).

As the MEGAPIE beam will register frequent shutdowns, the temperature inside the Pb-Bi liquid will fluctuate between 250°C and 420°C within 20 seconds time period. In order to estimate the induced temperature inside the fission chambers, calculations using CASTEM code have been performed. Results showed that the average working temperature of the chambers will reach about 450°C, with attenuated fluctuations due to the inertia of the whole assembly. Nevertheless, thermal fluctuations will be monitored with 3 K-type thermocouples placed at the levels of detectors.

3. Foreseen measurements

The absolute neutron flux will be measured at different positions with fission chambers at a level of few percent (as it was measured during tests at ILL using the same chambers, cables, connectors and electronics, see next section) despite the extremely unfavourable conditions.

Tab. 1. Characteristics of some flux monitors. Monitors are Ø 6mm ultra pure metal discs. The masses and reactions of interest are also indicated with the reaction energy threshold. A gamma analysis will be done 9 months after the end of irradiation.

Monitor	Mass [mg]	Reactions of interest	Half-life [day]	Gamma lines [keV]	Threshold Energy [MeV]
Al - 0.1% Co	5.576	^{59}Co(n,γ)^{60}Co	1925.6	1173 & 1332	thermal
Fe	9.889	^{54}Fe(n,p)^{54}Mn	312.1	834	0.7
Mn	20.4138	^{55}Mn (n,2n)^{54}Mn	312.1	834	10
Ni	11.565	^{58}Ni(n,p)^{58}Co ^{60}Ni(n,p)^{60}Co	70.88 1925.6	810 1173 & 1332	0.5 3
Rh	8.235	^{103}Rh(n,2n)^{102}Rh ^{103}Rh(n,p)^{103}Ru	207 39.25	475 & 511 497	10 1
Ti	14.7	^{46}Ti (n,p)^{46}Sc	83.81	889 & 1120	2.5
Y	15.776	^{89}Y(n,2n)^{88}Y ^{89}Y(n,p)^{89}Sr	106.61 50.55	898 & 1836 909	10 2

At the saturation plateau, the output current of a fission chamber is directly proportional to the neutron flux. For Uranium deposit chambers, this current *I* obeys the burn up law

$$I = \frac{N_a m \sigma_f \phi(t)}{\Gamma M} e^{-\int (\sigma_a + \sigma_f)\phi(t)dt},$$

where N_a is the Avogadro constant, *m* the mass of the deposit, *M* the molar mass of ^{235}U, σ_f the fission cross section, σ_a the neutron capture cross section, *t* the irradiation time, Γ a calibration coefficient determined prior irradiation, and ϕ the neutron flux. The ^{235}U burn up will reach 18 % after 6 months of continuous work. The deposit masses of the chambers were optimized in order to achieve working current *I* ranging from 1 to 100 μA. Thus, from the evolution of the current as a function of time it is possible to extract the absolute neutron flux but also all the variations observed on it.

The position of the chambers has been chosen to characterise the different components of the flux. Simulations using Monte Carlo MCNPX code have been performed [6] to estimate the average neutron fluxes in all detectors and the contributions of gamma rays. At the lowest position, inside the Gadolinium shielded chamber, the expected neutron flux will be of the order of 5.5 10^{13} n/cm^2/s with only 4 % of thermal neutrons. A contrary, at the upper position the estimated flux is 8.1 10^{12} n/cm^2/s with 74 % thermal neutrons.

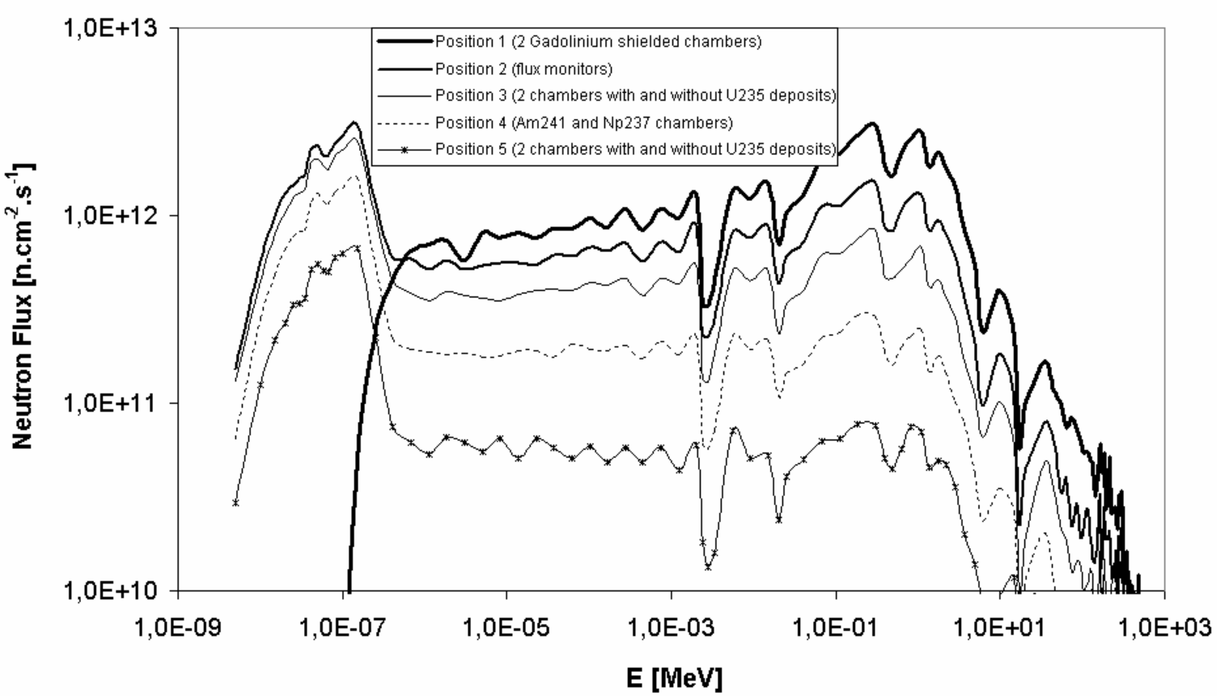
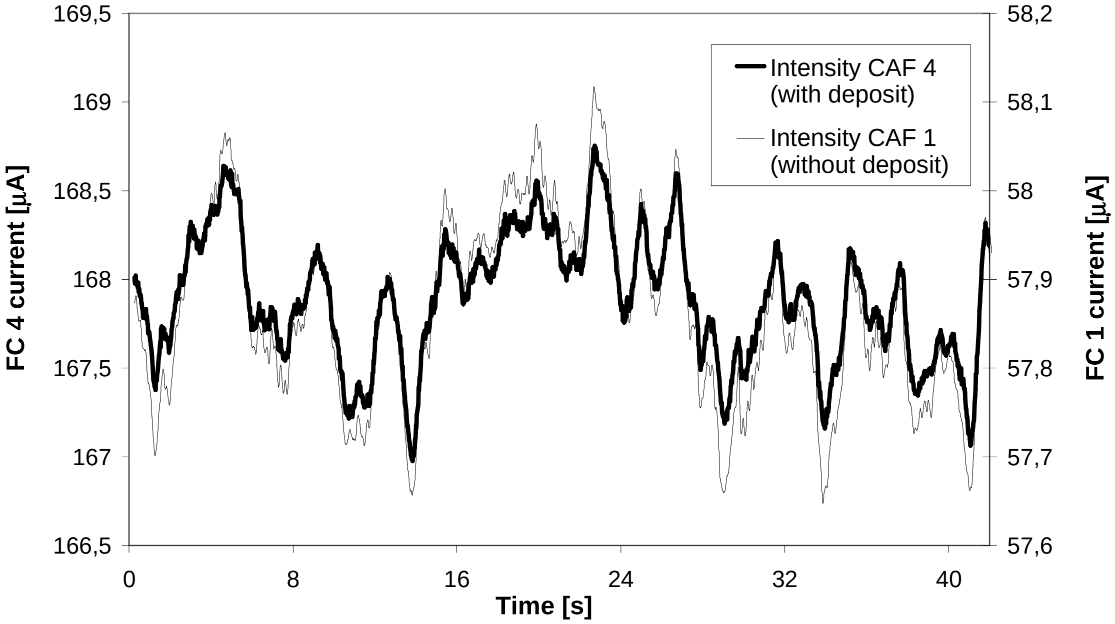


Fig. 2. Expected neutron flux spectra inside the detector at different distances from the target window.

All these information will help us to characterise as precise as possible the neutron flux of the MEGAPIE target and to study neutron fluctuations as a function of irradiation time, proton beam intensity, target and moderator temperature fluctuations, etc.

4. Tests at ILL and technical validation

The MEGAPIE chambers must stand 600°C and measure few µA in a noisy environment. For these reasons, new designed chambers have been developed and a special care has been accorded to the choice of cables, connectors and electronics. The prototypes have been successfully tested at the ILL High Flux Reactor within fluxes ranging from 7.10^{13} to 10^{15} n/cm^2/s. In such fluxes, 1 day at ILL is equivalent to 1 month at MEGAPIE in terms of thermal neutron fluency. Thus, the conditions of tests are largely above expected MEGAPIE conditions.



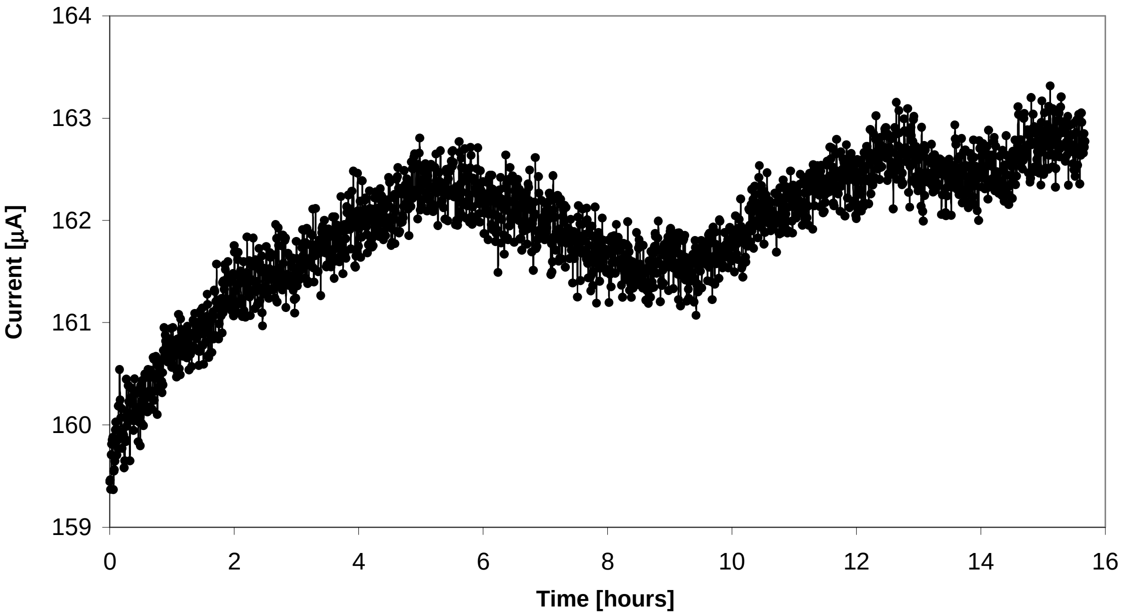


Fig 3 and 4. Fast (up) and slow (down panel) monitoring of neutron flux using ^{235}U deposit chamber measured at ILL.

In autumn 2003, 4 chambers have been irradiated during 43 days. They have performed a continuous measurement of the neutron flux at a level of 5 % and an on-line monitoring with a precision better than 1 %. Figures 3 and 4 illustrate this success and give an example of slow and fast recording of the flux.

During these tests, we have also proved the capability of these new detectors to stand high temperatures. In complement, two campaigns were performed, in summer 2004 and 2005, to study the transmutation of ^{237}Np and ^{241}Am in a 100% thermal flux. These data will serve as references for the MEGAPIE measurements in a 40% thermal flux. Data are still in analysis.

5. Conclusions

Neutronic performances of the MEGAPIE target will be measured using new designed fission micro-chambers. These detectors have been developed to stand MEGAPIE severe conditions and will perform absolute measurements of the neutron flux and on-line monitoring with high precisions. Prototype chambers have been successfully tested at ILL reactor for the last three years. They have proved their capability to resist high neutron fluencies and temperatures. The assembly of the complete Neutron Detector is in progress and the chambers have already been manufactured. Irradiations at PSI SINQ facility will begin mid 2006.

The data gathered during the 6-9 months of functioning on the neutron flux and on the incineration of two minor actinides will be of great importance for the next steps towards ADS demonstrators. In particular, the results will constraint models describing the physics of the spallation target and bring important information on the coupling of the accelerator with the reactor.

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