A novel micromegas detector for in-core nuclear neutron flux measurement

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A NOVEL MICROMEGAS DETECTOR FOR IN-CORE NUCLEAR REACTOR NEUTRON FLUX MEASUREMENTS

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Future fast nuclear reactors designed for energy production and transmutation of nuclear wastes need new neutrons detectors able to measure the neutron flux over a large energy range from thermal energies to several MeV. A novel compact and very small detector, named Piccolo-Micromegas has been developed for this purpose. Description of the detector configuration especially dedicated to neutron detection inside nuclear reactor is given. The advantage of this detector over conventional neutron flux detectors and the results obtained with the first prototype are presented.

1. Introduction

Micromegas is a gaseous detector [1] that has been developed initially for tracking in high rate high-energy experiments. At present, Micromegas detector is used in many experiments [2,3] and due to its high performances is being

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employed for searching rare events such as the Solar axion CAST [4] and also for neutron detection [5,6].

The detection principle is simple: the gas volume is separated in two regions by a thin micromesh, the first one where the conversion and drift of the ionization electrons occur and the second one, 50-150 micron thick, where the amplification takes place. In the amplification region, a high field (40 to 70 kV/cm) is created by applying a voltage of a few hundred volts between the micromesh and the anode plane, which collects the charge produced by the avalanche process. The anode can be segmented into strips or pads.

One of the main advantages of Micromegas is its robustness and its high resistance to radiations. These qualities have been exploited to develop a new detector to be used in nuclear reactor environment: operation with very high neutron flux, high gamma ray background and possibly at high temperature.

In order to be placed inside an empty rod of a reactor (see Figure 1a) the detector needs to be compact, sealed and very small (3.5 cm x 3.5 cm x 3.5 cm), contrary to the usual Micromegas detector used in particle physics experiments hence the origin of the Piccolo-Micromegas name.

After a short description of motivations, the full description of Piccolo-Micromegas is given. The advantage of this detector over conventional neutron flux detectors and the results obtained with the first prototype at the CELINA 14 MeV neutron source facility at CEA-Cadarache are presented.

2. Motivations

Fast nuclear reactors and Accelerator Driven Systems (ADS) are considered as an alternative for energy production and transmutation of nuclear wastes. One important step needed for approval of a demonstrator is the experimental validation of simulations. Of particular interest is the determination of the neutron spectrum (i.e neutron flux as a function of the neutron energy) for different configurations of the subcritical device. As well known, the neutron flux in ADS consists of neutrons produced via spallation reactions in the target and fissions from the multiplying blanket.

Unfortunately the neutron spectra cannot be measured using only one type of detector. To cover the complete energy range of the produced neutrons, a new neutron detector concept based on Micromegas technology has been developed.

For illustration the possible subcritical configuration based in TRIGA-ADS project which consists of coupling a 1 MW TRIGA reactor with a 140 MeV proton accelerator has been chosen [7]. The core has a cylindrical shape, the fuel rods being arranged in seven concentric rings labeled A to G. The central rod and the rods named ring B are reserved for the spallation target and its cooling system. The measurement can be only achieved starting from ring C. The distribution of neutrons in three-dimensional space as a function of energy and time is simulated using innovative simulation codes (FLUKA and EA-MC [8,9] at CERN, and MCNP-4C [10] at ENEA/Casaccia).

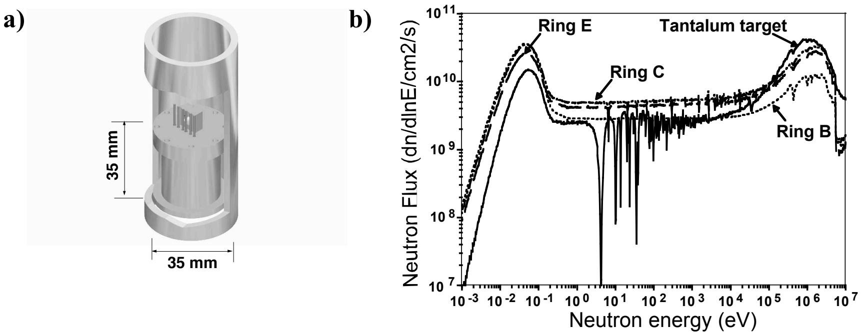

Figure 1. a) View of the detector Piccolo-Micromegas placed inside the empty rod of TRIGA b) Neutron flux spectra at selected locations of the TRIGA-ADS reference configuration

An example of the neutron energy spectrum for different regions of the core for $k_{src} = 0.97$ is given in Figure 1b. The measurement of neutron flux spectra is a necessary step in order to characterize the neutronics of the system.

3. Description of Piccolo-Micromegas

It has been demonstrated, from the results of CERN n_TOF experiments [11], that a Micromegas detector equipped with an appropriate solid neutron converter is well adapted for neutronic studies providing a fast response, a large dynamic energy range and a low sensitivity to gamma-ray background.

This method has been extended to the measurement of neutron flux in a nuclear reactor core. Fissile elements such as ^{235}U, ^{232}Th are used simultaneously as neutron/charged particle converter in addition to ^{10}B and recoil ions of the gas ($Ar + iC_4H_{10}$ quencher) filling the detector.

The Piccolo-Micromegas detector shown in Figure 2a is designed to cope with severe constraints encountered in a nuclear reactor environment (high radiation, high temperature, neutron activation, sealed detector). For this reason the detector structure, frames and sensitive elements have been carefully chosen and most of them are made out of stainless steel and ceramics.

The detector consists of a drift electrode, a thin stainless steel cathode grid and four anode pads connected to fast amplifiers. The drift gap is 1 mm wide and the amplification gap 160 μm. In a second prototype, different amplification gaps were used in each compartment, in order to adapt the dynamic range of the collected charge (see paragraph 4.1). Because of the high reactor temperature and the high radiation yield, the electronics were placed outside and connected to the anode pads through special radiation hardened and low capacitance coaxial cables 10 meter long.

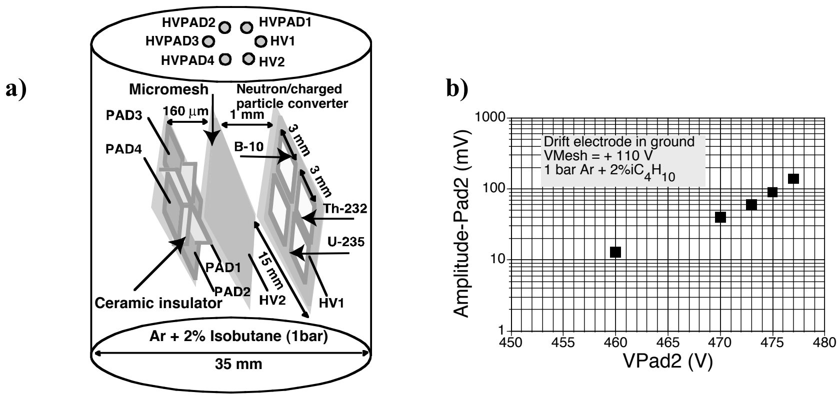

Figure 2. a) Schematic view of the Piccolo-Micromegas detector for neutron flux measurements inside a nuclear reactor. b) Variation of the amplitude of the signal of one PAD of Piccolo-Micromegas detector versus High Voltage (HV) of the PAD for fixed Mesh Voltage at +110 V, the drift cathode in the ground and 1 bar Ar+iC_4H_{10}.

The drift electrode is composed of four neutron/charged particle converters:

- ^{10}B for thermal and epithermal neutrons,
- ^{235}U for monitoring as the fission cross section of ^{235}U from thermal energies up to several MeV is well known,
- ^{232}Th with a fission threshold of about 1 MeV is dedicated to high energy neutrons.

The elastic scattering of neutrons with light atoms from the gas filling the detector (hydrogen) will produce nuclear recoils than could be detected with a typical threshold of several keV.

The use of the Micromegas read-out was motivated by the following advantages:

- a low sensitivity to gamma background has been demonstrated by many experiments [11,14]
- a high radiation resistance [12]
- a large dynamic energy range [11] allows for measuring simultaneously neutrons, alphas, fissions and recoil ions.
- a very good robustness

Using four converters with a unique detector will permit extracting practically on line a large range of the neutron flux spectrum in a specific position in the reactor. The large dynamic range of Piccolo-Micromegas will permit precise measurements and a detailed scanning of the flux into the whole reactor volume.

The use of the pre-mixed gas of ^{4}He + iC_4H_{10} or other quencher like CH_4 combined with the four neutron/charged particle converters before mentioned allows to obtain a large part of the neutron spectra of fast nuclear reactor and is well adapted to the requirements of the future ADS. At very high counting rate (>100 MHz) measurement will be performed on a current mode basis. At low counting rate, the fast response of the detector will allow counting one by one the incident particles using a low noise fast-preamplifier. It opens the way to measure the neutron flux at the peripheral part of the reactor and also in some cases when the full reactor power is not used.

4. Experiments and First results

4.1. *Characteristics of Piccolo-Micromegas detector*

^{55}Fe X-ray source and two types of gas mixtures (Ar-10%CO_2 and Ar-2%iC_4H_{10}) have been used to determine the main characteristics of Piccolo-Micromegas. The pressure of the sealed detector has been set to 1 bar. In order to adapt the dynamic range of the collected charges, two methods have been used:

1. Different amplification gaps in each compartment : this is ensured by the use of different thickness of anode pad.
2. To have more flexibility with the amplification gap, an identical amplification gap for the four pads (160 μm) has been chosen. The drift electrode is grounded. The mesh and the four reading pads have been individually positively polarized.

The signal from each pad is collected and shaped by a homemade fast amplifier. An oscilloscope-PC has been used for the data acquisition. The energy resolution of the detector at 5.9 keV ^{55}Fe X-ray is about 20%. The gain of the detector as a function of the voltage applied on the different pads has been measured (Figure 2b). The results show that a very low polarization of the pad is largely sufficient for the observation of the signal from fission fragments (several MeV compared to 5.9 keV energy deposited by the X rays of the ^{55}Fe radioactive source).

4.2. *Experiments and results with neutron source*

A first test with sealed prototype of the detector has been performed with 14 MeV neutrons given by the Cadarache CELINA facility. An example of the pulse obtained from the fission fragment emitted in the interaction of neutron s with ^{235}U is shown in figure 3a). This figure shows clearly the contribution of the detected electrons (fast part of the pulse) and ions (slow part) with a total width of 150 nsec. A special routine has been developed in Matlab Code [13] to analyze and clean the data for possible spark and saturation.

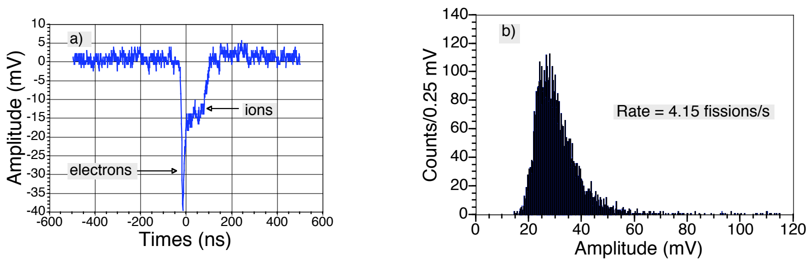

Figure 3. a) Example of the fission fragment pulse b) Amplitude spectrum of ^{235}U fission fragments

An example of the spectrum of ^{235}U fission fragment as a function of the amplitude of the pulse is reported in figure 3b). A full simulation of the Piccolo-Micromegas detector placed inside the CELINA-Cadarache neutron source facility has been performed using FLUKA code [8]. The study has been centered on the particular case of ^{235}U, because of the well-known fission cross section. For 50 μg of ^{235}U the measured fission rate given in figure 3b) is in good agreement with the prediction (4 fissions/s).

5. Conclusion

A new miniaturized Micromegas has been developed for the measurement of the neutron flux spectra in nuclear reactor. The first results presented here are obtained using a neutron source facility. The next step will be the measurement inside a nuclear reactor. Further improvements are necessary one of them is the use of special connectors and cables, in order to operate the detector at high temperatures, up to 300ºC.

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