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Piccolo Micromegas: first in-core measurements in a nuclear reactor

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Abstract

An Accelerator Driven System (ADS) consists in the coupling of an accelerator with a nuclear reactor. Such systems will need neutron detectors working in a wide energy range and insensitive to X- and γ-rays. Micromegas technology has been proposed to achieve this goal. The ability of Micromegas to detect neutrons over a wide energy range has already been demonstrated and this detector is, under certain conditions, insensitive to γ-rays. A new Micromegas neutron detector called Piccolo Micromegas has been designed to get integrated neutron fluxes on different energy domains. For the first time, Piccolo Micromegas has been placed in the core of a nuclear reactor at Casaccia in Italy. The configuration of the detector will be presented as well as its functioning and the reasons of its insensitivity to γ-rays. The results of the operation of the detector will also be shown for low reactor power to high reactor power ans some improvements will be suggested.

Key words: micromegas, neutron detection, ADS, nuclear reactor

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1 Introduction

Nuclear energy represents 30% of Europe's electricity, ensuring energy supply security and oil independance combined with low emission of green house gases. However, sustainable development and public concern require a permanent and reliable solution to nuclear radioactive waste. The present leading approch is waste disposal in deep geological formations, which raises problems of site selection, public approval and also long term reliability. Accelerator Driven System (ADS), which consist in the coupling of an accelerator to a target installed in the center of a nuclear reactor, are viewed today as one of the possible ways to reduce the nuclear waste volume and the long term toxicity. It has been experimentaly demonstrated that an ADS has the potential to produce energy [1] but also to destroy nuclear waste [2]. It can also be used for radioactive isotope production, for example for medical applications [3]. ADS has been studied through several experiment projects around the world like the TRADE project[4]. These hybrid systems are safer than classical nuclear reactors since they work in a sub-critical state. Moreover, they produce less plutonium and nuclear waste when they use a fuel based on thorium oxide. These new systems need experimental data on their neutron flux in order to confirm or improve simulations. Neutrons are produced by spallation reactions in the target and fission reactions in the fuel. Measuring the neutron energy spectrum would be particularly interesting. Because of the accelerator and the charged particles hitting the target, a lot of γ-rays are produced and it is during this high γ flash that neutrons have to be detected. A neutron detector based on the Micromegas concept [5] has been realised for use with an ADS. Insensitive to γ-rays in certain conditions, this detector is able to work either

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in counting or in current mode to detect neutrons in wide neutron energy range for low or high fluxes. Micromegas has already worked as a neutron detector for n_TOF (Neutron Time Of Flight) at CERN in 2001 [6,7]. More recently, some studies have been realised in high γ flux environments for the DEMIN project [8]. An other experiment called INPHO has lately demonstrated the ability of Micromegas to detect fast neutrons in a γ flux higher than $10^{10}\,\gamma/\mathrm{cm}^2/\mathrm{s}$ [9]. It was then natural to try to use Micromegas in the ADS framework. The Piccolo Micromegas detector is presented first with the functioning principle and a technical description. The results obtained from measurements in a nuclear reactor are then reported and some improvements are proposed.

2 The neutron detector 'Piccolo'

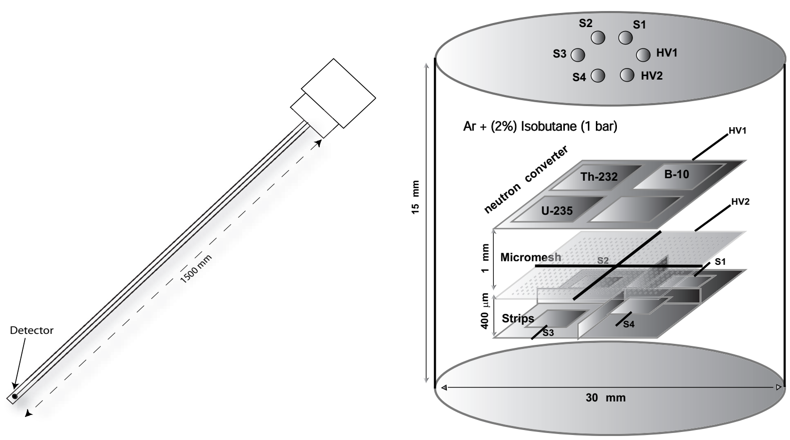
This new detector, named Piccolo for its small size, was designed in 2004 for the TRADE project and it has already been tested with a neutron generator in 2005 [10].

2.1 Detector principle

The Piccolo detector is based on Micromegas technology. Micromegas is a gaseous detector composed of two stages separated by a micromesh: a drift or ionization space with a low electric field ($\simeq$ 1 kV/cm) and an amplification space with a high electric field ($\simeq$ 10 kV/cm) [5]. Electrons, produced by the passing of charged particles through the gas, drift toward the micromesh under the action of the low electric field. A funnel is created by the field lines around the micromesh and allow the electrons to pass through it and to be multiplied in the amplification gap. This avalanche creates a current on the anode strips. However, neutrons have to be converted into charged particles in order to be detected by ionization. This can be done by two means, either by elastic collision of the neutrons on gas atoms or by the use of a deposit of ^{10}B, ^{6}Li, or ^{235}U for example, at the entry of the ionization space. Three deposits are used here: ^{10}B through the ^{10}B(n,α) reaction (50 μg), ^{232}Th (140 μg) and ^{235}U (50 μg) through their fission reaction. The gas used here is a mixture of argon+isobutane(2%) which is a non-flammable gas. A detector part without any deposit is used to detect the recoils of hydrogen coming from isobutane. The use of different converters allows the detection of neutrons in several energy domains. Boron and uranium permit the measurement of neutrons from the thermal energy to 1 MeV while the thorium fission has a threshold of about 1 MeV. Recoil protons are detected from the threshold energy of the detector to several MeV. Obviously, fission products ionize much more than an alpha particle coming from boron or from hydrogen recoils. Despite the common micromesh, it is possible to get different gains in each detector by applying a different voltage on each pad. Moreover, the detector has a wide dynamic range since it can work in pulse mode at low fluxes and in current mode at higher ones.

2.2 Technical description of Piccolo Micromegas

This new detector is placed in a long cylindrical chamber made of stainless steel with 35 mm external diameter, 30 mm internal diameter and long enough to reach the top of the reactor core (see figure 1.a). This small diameter allows the placement of the chamber inside an empty rod of a TRIGA type reactor and to make in-core measurements. The detector is handled at the end of this chamber by a stainless steal rod. In order to use the detector in sealed mode, The chamber is hermetically closed at the top with watertight connections for the signals, the high voltages and the gas. This micromegas detector is in fact composed of 4 micromegas detectors of 5 mm^2 with a common 30 μm thick stainless steel micromesh (see figure 1.b) of 500 LPI. Six wires, going from the detector to the top of the chamber, are necessary to connect the 4 cathode pads, the micromesh and the drift electrode. The common drift electrode is put on a ceramic piece with 4 holes of which one was empty and 3 were holding different neutron converter materials. The drift electrode touches the converter holders to ensure electrical conductivity. The drift gap is 1 mm in the case of the three deposits whereas it is 3 mm for the empty one. The 160 μm amplification gap is ensured mechanically by a stainless steal piece with 4 holes. Contrary to a classical micromegas detector, there is no need for spacers thanks to the small dimensions of the holes diameter. In that case, the micromesh is not warped by the amplification field. Concerning the thermal aspects, a special effort has been made so that the detector supports high temperature with no important gain variation. Moreover, the use of ceramics and stainless steel permits to reduce the activation by the neutron flux.



(a) (b)

Fig. 1. (a) Cylindrical chamber handling the detector, (b) the conceptual design of the Piccolo detector.

Two working modes have been used, pulse mode or current mode when the counting rate was too high (when the reactor power was high). In current mode, the current is just read out on the high voltage module [1] of the micromesh and the pads. All the other electronic modules consuming current like high voltage filters for the pads or the micromesh preamplifier [2], are bypassed in order to determine the real detector current.

In pulse mode, the signal of each pad is fed through a fast preamplifier (2 ns of rise time and 50 of gain). These preamplifiers are linked to 1 GHz ADC [3] flashes interfaced to a labview-based data acquisition program by a VME-PCI optical link bridge module [4]. The whole system is running at 60 Hz with four channels and allows to register the pulses. The preamplifiers are also linked to level discriminators and scalers in order to perform some counting rate measurements.

3 Piccolo micromegas in a nuclear reactor

The Piccolo detector has been tested inside a 1 MW TRIGA (Training, Research, Isotopes, General Atomics) nuclear reactor of the ENEA center of Casaccia (Italy) in sealed mode during two weeks. Measurements have been performed with the reactor operating at a power ranging from 10 W to 400 kW at two different positions inside the reactor (on the periphery and in the middle). At low power, measurements were realized by simple counting on

[1] N471A from CAEN
[2] 142B from ORTEC
[3] V1729 from CAEN and [11]
[4] V2718 from CAEN

the pads while at higher power only the current delivered by the high voltage can be registered since the counting rate is too high. This experiment aims at studying the behavior of the detector inside a nuclear reactor. Several problems has been tackled like the linearity of the response versus the reactor power or the aging. The output energy spectra corresponding to the different converters have also been studied, which allows a good understanding of the detector response.

3.1 Description of the TRIGA reactor

3.1.1 The TRIGA RC-1

The 1 MW TRIGA reactor of ENEA-Casaccia is a pool thermal reactor with a core contained in an aluminium vessel and placed inside a cylindrical graphite reflector, bounded with lead shielding. The biological shield is provided by concrete having a 2.2 m mean thickness. Demineralized water, filling the vessel, ensures the functions of neutron moderator, coolant and first biological shield. Reactor control is ensured by four rods: two shim rods (SH1 and SH2), one fuel-follower safety rod (SEC) and one regulating rod (REG). Produced thermal power is removed by natural water circulation trough a suitable thermohydraulic loop composed of heat exchangers and cooling towers.

3.1.2 The core

The reactor and the experimental facilities are surrounded by a concrete shield structure. The core and the reflector assemblies are located at the bottom of an aluminium tank (190.5 cm diameter). The overall height of the tank is about 7 m. Therefore, the core is shielded by about 6 m of water. The core, surrounded by the graphite reflector, consists of a lattice of fuel elements, graphite dummy elements, control and regulation rods (see figure 2). There are 127 channels divided in seven concentric rings, named A through G, each containing a number of channels ranging from 1 to 36. One channel houses the start-up Am-Be source, while two fixed channels (at the center and at the periphery) are available for irradiations or experiments. A pneumatic transfer system allows fast transfer from the peripheral irradiation channel and the radiochemistry end station.

The diameter of the core is about 56.5 cm while the height is 72 cm. Neutron reflection is provided by graphite contained in an aluminium container which is surrounded by 5 cm of lead acting as a thermal shield. The core components are contained within top and bottom aluminium grid plates: the top grid has 126 holes for fuel elements and control rods and a central thimble for high flux irradiations. The reactor core is cooled by natural convention of the water in the reactor pool.

3.1.3 The fuel

The fuel elements consist of a stainless steel clad (AISI-304, 0.05 cm thick, 7.5 g/cm^3 density) characterized by an external diameter of 3.73 cm and a total height of 72 cm end cap included. The fuel is a cylinder (38.1 cm high, 3.63 cm diameter, 5.8 g/cm^3 of density) of a ternary uranium-zirconium-hydrogen alloy (H-to-Zr atom ratio is 1.7 to 1; the uranium, enriched to 20% in ^{235}U, makes up 8.5% of the mixture by weight: the total uranium content of a rod is 190.4 g, of which 37.7 g is fissile) with a metallic zirconium rod inside (38.1 cm high, 0.5 cm diameter, 6.49 g/cm^3 of density). There are two graphite cylinders (8.7 cm high, 3.63 cm diameter, 2.25 g/cm^3 of density) at the top and bottom of the fuel rod. Externally two end-fittings are present in order to allow the remote movements and the correct locking to the grid.

The regulation rod has the same morphological aspect as the fuel rod: the only difference is that instead of the mixture of the ternary uranium-zirconium-hydrogen alloy, there is the absorber (graphite with powdered boron carbide). The control rods are "fuel followed": the geometry is similar to that of the regulation rod with the bottom graphite cylinder replaced with fuel. The graphite dummies are similar to the regulation rod but without boron inside the central volume.

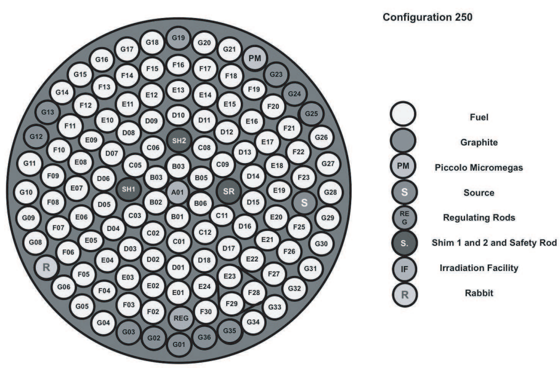


Fig. 2. TRIGA reactor configuration and position of the Piccolo Micromegas detector in the periphery of the core (for the central position, Piccolo was placed in $D18$).

3.2 Data analysis

The study of the linearity of the response as a function of the power is quite straightforward. At high power, the current can be read on the high voltage module. At low power, one has to count the number of reactions detected on each pad on the scaler. The triggering of the scaler is realized with a discriminator module with a threshold tuned to be equivalent to the threshold of the VME acquisition used to register the pulse. However, one has to choose correctly the micromesh and the drift electrode voltage.

Concerning the pulse analysis, each pulse registered by the ADC is processed via a C++ home made program. The pulse amplitude, its time length and its area (proportional to the energy deposit) are then calculated. However one has to be sure to detect neutrons and not γ-rays or simply noise, which can be very high in a nuclear reactor. One example of a pulse registered with Matacq is shown on figure 3.

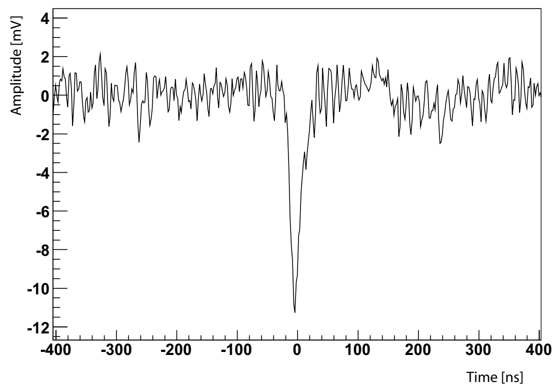


Fig. 3. Signal registered on the ^{10}B Matacq channel at P=10 kW.

3.3 Working conditions

The noise has been evaluated by determining at the variation of the baseline which has a RMS value of 1 mV. Since the threshold of the VME acquisition is 6 mV, electronic noise can be neglected. Moreover, the mean energy of the noise (that is to say the area between the baseline and the noise oscillations) is around 8 mV.ns. This value is much lower than the one observed on the energy spectra of the nuclei coming from the neutrons conversion.

The γ-ray flux inside the reactor with is about 10^9 $\gamma/\text{cm}^2/\text{s}$ in the center of the reactor at 100 kW. It can be detected by operating Piccolo at high gain (with a micromesh voltage of about -350 V which gives an electric field of 22 kV/cm) but there is no need to apply such a high voltage for charged particles. Figure 4.a shows the counting rate of Piccolo inside the reactor switched off

(P=0). In this case, γ-ray is the only one radiation passing through piccolo, coming from the activation of the reactor material. The figure confirms that Piccolo, under a high voltage of 330 V in absolute value, is not sensitive to gamma rays while at higher gain the counting rate increases drastically.

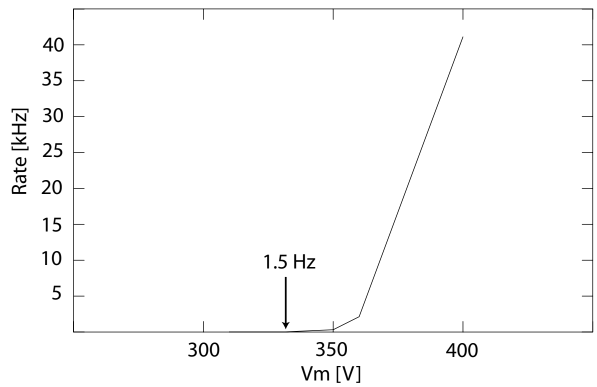


Fig. 4. Piccolo counting rate versus the absolute micromesh voltage at P=0.

The detection of H recoils needs high gain. However, the detector sparks because of the recoils of carbon and argon atoms (which ionize much more than hydrogen recoils) if the reactor power is high enough to produce a high neutrons flux and if the potential difference between the pad and the micromesh is over 300 V (in absolute value). Thus, the working voltage was set to -270 V for the ^{10}B and the recoil pads. For the two fission pads, since the energy deposit of fission fragments is high, a micromesh voltage of -190 V was enough. To obtain these two different working voltages with the common micromesh, the micromesh voltage was fixed to -100 V while the fission pad voltages was $+90$ V and the boron and recoil voltage was $+170$ V. Considering the chosen working voltage values, the gain is lower than the one used during the INPHO experiment by at least a factor of 10, ensuring a good γ rejection [9].

The current versus the micromesh voltage on two pads (uranium and boron) at 10 kW is shown in figure 5. From this curve, it is possible to evaluate the detector gain which is about 10 for the uranium and thorium converters and

30 for the boron and gas converters (H recoil). Therefore, by comparing the Piccolo set up to the n_TOF set up [7], it has been possible to evaluate the detection threshold to 400 keV for the boron and gas converters. The threshold is quite high, which is normal at low gain.

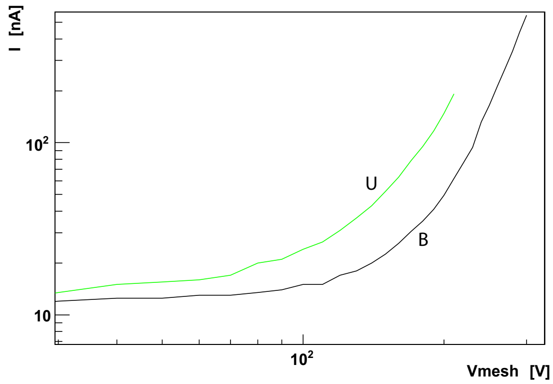
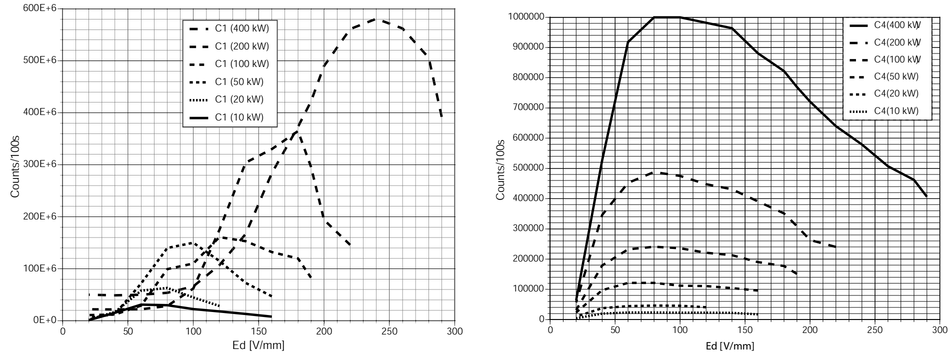


Fig. 5. ^{10}B and ^{235}U Pads current versus the absolute micromesh voltage at $P = 10$ kW.

3.4 Drift voltage influence

Fixing the micromesh voltage is not sufficient, one has also to choose the drift voltage. Usually in this argon mixture, a field of about 50 V/mm is enough to get optimum results in terms of charge transfer through the micromesh. Figure 6 shows the counting rate dependence of the uranium and of the thorium pad with the drift field for different reactor powers. On the uranium pad, for each power an optimum in the counting rate exists and the corresponding field value increases with the reactor power. It goes from a normal value of 60 V/mm at 10 kW to 250 V/mm at 400 kW. On the contrary, the optimum value for the thorium pad doesn't move with the reactor power.

Since the neutron flux is important in the reactor (about 10^{11} n/cm^2/s at 10 kW), the reaction rates of each pad, and more especially the uranium or the boron pad, are very high. A large number of electrons are created and some



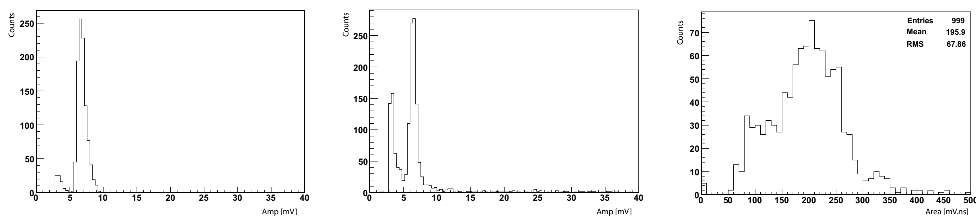
(a) (b)

Fig. 6. Counting rate on the uranium part (a) and on the thorium part (b) versus the absolute drift voltage and for reactor powers from 10 to 400 kW.

space charge effects appear in the detector which degrades the drift field. In that case, it is necessary to increase the drift voltage in order to counterbalance the space charge and sweep the electrons towards the amplification gap. In the case of thorium, the reaction rate is much lower because of the fission threshold and there is no space charge effect. In the rest of this article, all the currents and the counting rates will be given at the optimum value of the drift voltage.

3.5 Spectral analysis

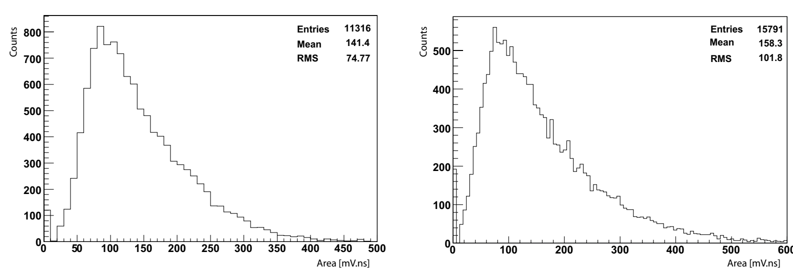
The spectral analysis has also permitted to observe the space charge influence. Figures 7.a and 7.b present two amplitude histograms from the boron converter with two different values of the reactor power increasing from left to right. Two peaks appear on these histograms. The detector is not able to distinguish α particles from ^{7}Li particles and even if these two peaks were representing the two reaction products of the neutron absorption, they shouldn't be so well separated. The lower peak in amplitude is not noise since the noise level is at 1 mV. This lower peak gets more important compared with the second with the increase of the power. It is another indication of the space charge effects in the detector with two functioning modes taking place at the same time: one of normal amplitude with a total collection of charges and one of low amplitude with only a partial collection appearing probably on the periphery of the pads. The third figure (7.c) presents an energy spectrum from boron at 10 kW. Like the amplitude histogram, two components can be seen in this spectrum, one of low energy (mean value around 120 mV.ns), degraded, and one of high energy (mean value around 210 mV.ns).



(a) (b) (c)

Fig. 7. (a) Amplitude histogram from the boron converter at 100 W (b) and 10 kW, (c) energy histogram from the boron converter at 10 kW.

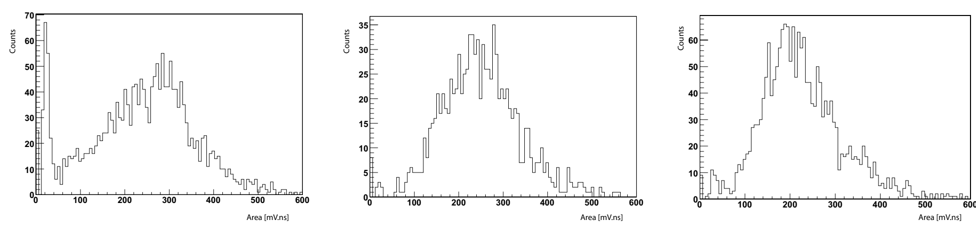
The figures 8 show the energy spectra from boron and uranium with an optimized drift voltage. In that case, the spectra look homogeneous with no space charge effect (to be compared to the figure 7.c). However, it's not possible to separate the two peaks of the uranium fission.



(a) (b)

Fig. 8. Energy spectra from boron at 200 kW (a) and uranium at 400 kW (b).

The outgassing from its inner material modifies the gas features. The signal amplitude induced by α particles coming from the radioactivity of thorium or uranium has been measured during several days to estimate the gain evolution. The gain has decreased by a factor of two in two weeks, which can be compensated by decreasing the mesh voltage of -30 V. Moreover, the avalanche occurring in the amplification gap leads to a deterioration of the gas (breaking of the isobutane molecule) and of the micromesh (carbonization) and it is of course worse at high counting rates. Micromegas has already been tested with a ten years equivalent LHC radiation showing no change in the gain [12]. Figure 9 shows three energy spectra of the fission fragments coming from uranium for three consecutive days. One clearly sees a decrease of about 30% on the mean energy.



(a) (b) (c)

Fig. 9. Uranium converter energy spectra at 10 kW for three consecutive days.

A total decrease of a factor of 2.5 has been observed during the 10 days of test in the TRIGA reactor. It has not been possible to estimate if it was coming from the normal outgassing or from the deterioration of the isobutane, this would need long term dedicated studies.

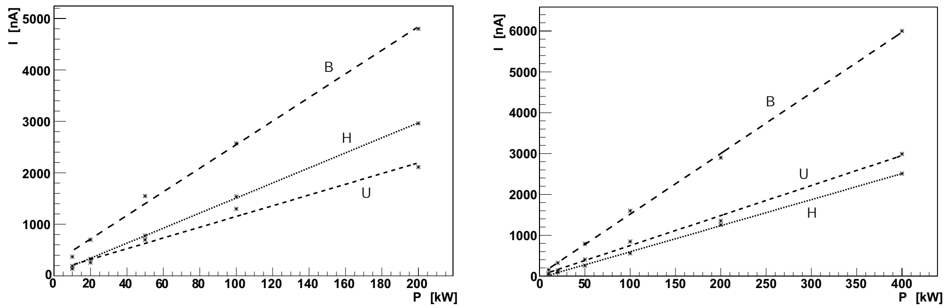
Concerning the burn up, the most critical deposit is the ^{10}B with its huge thermal cross section. It could be used only several days at 100 MW for example. However, during our tests, the power hasn't exceeded 400 kW. On this point of view, the gas recoils are interesting since the number of atoms is higher than for a thin deposit and this converter could last a long time.

3.7 Influence of the temperature

In the laboratory, during preliminary tests, the detector has not been heated at higher temperatures than 100°C, which was the temperature applied on the shield during pumping (to outgas the detector material) and before gas filling. However, the influence of the temperature on the signal has not yet been measured. The water temperature inside the TRIGA reactor was not exceeding 30°C at 200 kW while the temperature of the uranium fuel was reaching 140°C. Although the detector can not be heated up by the converters neutron absorption, it could be heated by the high ambiant radioactivity (300 rad/h/W) leading to an energy deposit from γ- and β-rays in the detector material. It has been estimated that the temperature could have increased up to 200°C during the test. During one hour at 200 kW, it has been observed that the thorium pad current remained constant, the uranium pad current increased by 5%, the boron by 20% and the recoil pad by 25%. If this increase were due to activation, it would have increased also on the thorium pad like on the uranium pad of the same absolute value. This increase is proportional to the current and to the gain. Hence, it corresponds to a gain variation probably due to the temperature and the consecutive dilatation. The increase of the boron or the recoil pad gain is compatible with simulations showing that one could get 3% more gain per micron amplification gap decrease and per 100°C of temperature increase.

The figures 10.a and 10.b present the current of three pads corresponding to the uranium, boron and hydrogen recoil converters, as a function of the reactor power in the center and at the edge of the reactor. First of all, all the currents are linear with the power which is a first step towards the feasibility of power measurements with this detector. The thorium converter current is not shown since it was too small to be measured with this set-up due to its low reaction rate. The boron current is the highest because it has a higher gain (with the proton recoil pad) and the higher reaction rate. Moreover, the central measurement (figure 10.a) has been made after 1 hour at 200 kW while the edge measurement has been made directly from 10 to 400 kW at the reactor switching on. The central measurement is then correlated with the activation of the nuclear materials inside the reactor or with the temperature detector increase. It is one of the reasons why the proton recoil current is higher than the uranium current in the center although it was lower at the edge. The proton recoil pad is much more sensitive to temperature since it has a higher gain. The current measurement is also sensitive to γ-rays coming from the fission process inside the reactor. It is not a problem for the uranium and boron converters since their reaction rate is high and their drift gap is very low. Their currents are mainly due to neutron reactions. However for recoils, the drift gap is three times larger and the current due to recoils is probably of the same order than the one induced by γ-rays.

The figure 11.a and 11.b show the counting rates as a function of the reactor power. They should be, in the same manner than the current, linear with power. For the thorium converter (figure 11.a), it is the case, it is perfectly linear with the power in the two positions. For the other converters, the lin-

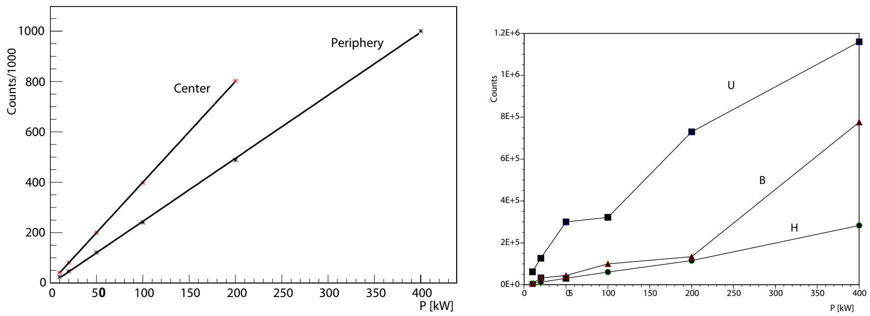


(a) (b)

Fig. 10. Currents versus reactor power in the center (a) and at the edge (b) of the reactor for the uranium, boron and hydrogen recoil pads.

earity is not respected anymore for different reasons. Concerning uranium, the reaction rate was too high for the scaler and the linearity is visible only from 10 to 50 kW before the scaler begins to be limited. Concerning the two last pads, H recoil and boron converter, one has to remember that the detection threshold was 400 keV. Only a negligible part of the reaction products (proton recoils, α and ^{7}Li) deposit enough energy. It is in that case difficult to interpret the results even if the linearity of proton recoils counting is not so bad. However, these counting rates measurements are very interesting since they are totally insensitive to activation and γ rays and could permit to make absolute measurements of the reactor power. On the contrary, it would be very difficult without any reference detector to make a current measurement uncorrelated with γ and β rays. The reaction rates have been evaluated by MCNP simulations using a simulated flux of this TRIGA reactor realized in the LPC/Caen laboratory. The measured reaction rates are much lower than those which have been simulated, still because of the threshold, by a factor of 10 less for thorium to 10^5 for boron.

The current (or counting rate for thorium) ratio between center and periphery is presented on figure 12. Uranium and thorium converters give the same ratio,



(a) (b)

Fig. 11. Counting rates versus reactor power on 100 s: (a) for the thorium pad at the edge and in the center, (b) for the other converters at the edge (divided by 500 for the uranium pad).

about 1.7, between center and periphery, which is a realistic value. The result is found by counting for thorium and current for uranium and it is confirmed by the boron converter at high power. It means that the ratio is valid for low energy and for high energy neutrons. However, at low power, the boron current increases since the measurement begins to be sensitive to activation. For the recoils, the current is sensitive to both γ-rays from fission (ratio over 2.5) and from the activation (ratio increases at low power). The γ flux ratio (about 3 following General Atomics data) between center and periphery is higher than the neutron flux ratio, which explains the results obtained with proton recoils.

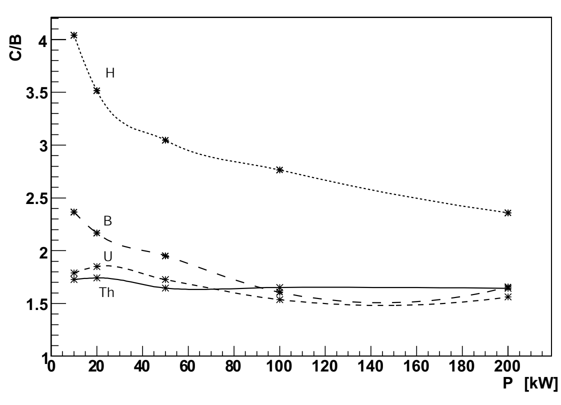


Fig. 12. Ratio of the central current to the edge current (except for thorium for which it is the counting rates ratio).

The first experimental results obtained in the core of the reactor are rather promising. They indicate a good behaviour of the Piccolo Micromegas detector.The counting mode is important for the purpose of background rejection allowing, for instance, γ and β particle discrimination. The detector energy threshold has to be decreased without degrading the γ-ray insensitivity. In order to optimize the performance of the detector, the following improvements are proposed:

- Switching to helium gas would allow to reach a higher gas gain or to improve the sparking limit [13].
- Employing low-noise fast charge preamplifiers would improve the signal to-noise ratio by more than a factor of ten.
- For low-energy neutrons, it would be sufficient to use only an uranium target, a lower counting rate is expected and the larger energy deposition will provide signals of high amplitude.

The various improvements are expected to significantly improve the detector operation and provide comfortable signals at even lower gains; low gain operation is a great step forward to avoid the build-up of space charge and diminish detector aging. Mechanics should also be modified and optimized to avoid as much as possible space charge effects and gain variation with temperature. All these modifications would allow to greatly improve the results.

4 Conclusion

The performances of a Piccolo-Micromegas prototype have been studied in the core of a nuclear reactor. Up to the highest reactor power (400 kW) measurements in both continuous (read-out of the cathode current) and counting mode (anode strip read-out) have shown a good linearity with power. The behaviour of the detector inside the reactor under high neutron and γ-ray fluxes has been well understood. Piccolo could perfectly fit the requirements of the future ADS project and perform neutron flux measurements. However, some geometrical modifications are necessary to optimize the detector and especially the electric field configuration in the drift compartment. The choice of a more appropriate gas filling shoud be studied and an adequate low-noise electronics is necessary to decrease the energy threshold. Moreover the long term aging of the detector, which is an important issue in the case of sealed gaseous detectors, would merit a long term dedicated study inside a nuclear reactor.

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