DIRECT EXPERIMENTAL TESTS AND COMPARISON BETWEEN SUB-MINIATURE FISSION CHAMBERS AND SPND FOR FIXED IN-CORE INSTRUMENTATION OF LWR

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Abstract

A fixed in-core instrumentation is an attractive tool for future LWR in order to obtain precious information on the core status (transient follow-up, on-line 3D neutrons flux and power map...). In this context, CEA laboratories have a great experience of the neutron detectors which are major candidates for such instrumentation: Sub-miniature Fission Chamber and Self-powered Neutron Detector. In order to compare advantages and disadvantages of each detector, a direct experimentation is being carried out in the SILOE research reactor. The design of the experiment, the different results and their interpretation are presented in this paper.

Introduction

A fixed in-core instrumentation represents a significant improvement for future LWR in order to obtain precious information on the core status (transient follow-up, on-line 3D power map and neutron flux...). In this context, CEA laboratories have a large measure of experience concerning the neutron detectors which are major candidates for such instrumentation: Sub-miniature Fission Chamber and Self-powered Neutron Detector [1,2].

In order to compare the advantages and disadvantages of each detector, two direct experimentations are being carried out at the Siloe Research Reactor: the first one which is under way at the moment (March-November 1996) consists of the comparison between Sub-miniature Fission Chambers and Rhodium SPNDs (e.g. concerning the “static mode” of the reactor). The second one, which is planned for 1997 (January-September 1997), will consist of the comparison between Sub-miniature Fission Chambers and prompt SPNDs such as hafnium, platinum and cobalt (e.g. concerning the “transient mode” of the reactor).

After a description of the detectors, the design of the experiments is presented. Finally, the first results and their interpretation are given and discussed.

The detectors

Sub-miniature Fission Chamber (SMFC)

Compared to the classical 3 mm diameter fission chamber usually used for mobile instrumentation in LWRs, a technological gap has been made in order to perform a fixed in-core instrumentation; due to the fact that six or seven neutron detectors have to be located axially, a maximum diameter of 1.5 mm is necessary. This led us to design a new technological sub-miniature fission chamber containing about 200 µg of fissile material (^{235}U or ratio ^{234}U/^{235}U for regenerating deposit) with a tight “feedthrough” between the fission chamber body and the coaxial wire (see Figure 1). Such a detector is expected to have an efficiency of about 10^{-18} A/n.cm^{-2}s^{-1} and to be directly sensitive to neutron flux. However, a fission chamber needs a power supply ($\approx$ 30 volts) and with such a geometry (detector body Φ: 1.5 mm, length: 25 mm, coaxial wire $\leq$ 30 meters) needs a careful design to avoid insulation leakage [1]. One of the big interests of the experiment is to know the behaviour of this tight “feedthrough” (n° 6 of Figure 1) under high temperature and high neutron and gamma dose rate.

Self-powered Neutron Detector (SPND)

As explained before, in the first experiment, only Rhodium SPNDs are used and in the second one, it will be a question of hafnium, platinum and cobalt (this second step being oriented to the transient follow-up). Different shrouding of the detectors (for example steel shrouding) could be used in order to optimise the neutron detection and to evaluate separately: the thermal sensitivity, the epithermal neutron sensitivity and the gamma sensitivity [2,3].

The experiments

The experimental tests are and will be performed in the research and irradiation SILOE reactor (water reactor of 35 MW located at the CEA centre in Grenoble). This “modular” reactor uses plate fuels and has some positions with intense thermal neutron flux (between 5.10^{13} $n.cm^{-2}s^{-1}$ and 10^{14} $n.cm^{-2}s^{-1}$). Such positions are interesting for testing the mechanical behaviour of the detectors under high neutron and gamma dose rate (leak of insulation?).

For the purpose explained above (direct comparison between Fission Chamber and SPND), two experiments are planned. They are described below.

The CAFET experiment (ChAmbres à Fissions En Temperature)

This first experiment is being carried out at the moment (March-November 1996) and concerns the “static mode” of the reactor. The CAFET device consists of a thimble in aluminium insulated, from a thermal point of view, with helium gas (see Figure 2).

The thimble contains two Sub-miniature Fission Chambers, two Rhodium SPNDs, two thermocouples, a heating coaxial and two copper-cobalt activation detectors, these last two being necessary to evaluate, at the end of the irradiation time, the absolute thermal neutron fluence (it will be about 10^{21} $n.cm^{-2}$).

The power deposit on the metallic structure due to particle rays (about 2.4 W/g at the thimble location) induces the major part of the heating inside the thimble. A temperature adjustment is also possible using the heating coaxial located inside the thimble.

The behaviour of the neutron detectors versus the temperature (especially the Rhodium SPND number 084 and 085 – see Figure 2) can be compared to other SPNDs located outside the thimble (SPND number 082 and 083 from Figure 2) which are at the temperature of the reactor coolant water (about 35°C).

This CAFET experiment allows us to obtain, for each stabilised irradiation level (e.g. percentage of full power), the following parameters:

- Global efficiency (A/n cm-2.s-1);
- Statistical uncertainty;
- Linearity of the detector response versus the reactor power;
- Effect of temperature;
- Behaviour of the insulation (especially for Sub-miniature Fission Chambers).

The VARAPPE experiment (VAriation RApide de PuissancE)

This second experiment will be carried out between January and September 1997 and will concern the “transient mode”. The VARAPPE device is especially designed for the study of the dynamic characteristics of Fission Chambers and prompt SPNDs. It consists of placing in a stainless steel thimble, two Sub-miniature Fission Chambers and various prompt SPNDs with different emitting material such as: hafnium, platinum and cobalt (see Figure 3). The transient mode will be obtained by vertically moving the detectors in front of a cadmium foil at a speed of about 1 ms^{-1}. For each detector, it should be possible to evaluate:

- The response time;
- The prompt current part obtained with the moving compared to the equilibrium signal.

Technological improvements of SPND performed in order to improve the insantness will be tested during this second experiment (compensation of the sheath current, minimisation of the current coming from γ ray...) [4].

First results and interpretation

An irradiation cycle of the SILOE Reactor (about one month) consists of three phases:

- At start-up, different steps of neutron flux at different percentages of nominal power;
- A long stable phase at nominal power;
- A slow shutting down of the reactor at the end of the cycle.

The value of the neutron flux inside and outside the thimble has been evaluated using the APOLLO neutron transport code [5]. Previous work has indicated the good confidence of this approach.

The Sub-miniature Fission Chambers (SMFC)

For the different irradiation levels, the two SMFCs follow, very precisely, the value of the thermal neutron flux as indicated in the table below (and in Figure 4):

Power Reactor (MW)	Thermal Neutron Flux (n.cm-2s-1)	Average signal det 1 (volts)	Average signal det 2 (volts)
15	4,42 10^{13}	0,350	1,050
20	5,78 10^{13}	0,452	1,276
25	7,14 10^{13}	0,541	1,512
30	8,23 10^{13}	0,597	1,716
35	9.89 10^{13}	0,659	1,986

Such acquisitions lead to the following results:

- There is a very good linearity between the signals and the neutron flux;
- The efficiency ε_1 of Fission Chamber number 1 is about 7 10^{-19} A/n.$cm^{-2}s^{-1}$;
- The efficiency ε_2 of Fission Chamber number 2 is about 2 10^{-18} A/n.$cm^{-2}s^{-1}$. This difference between detector 1 and 2 is due to the difference of ^{235}U deposit inside the SMFC (70 µg for detector 1 and 200 µg for detector 2);
- The statistical uncertainty (at 2 standard deviation) is of 4% for detector 1 and of about 2% for detector 2 (for the full operating range);
- There is no change in the behaviour of the SMFC due to either temperature or neutron and gamma irradiation (the insulation resistance without flux is about 10^{11} Ω);
- The signal loss due to the consumption of ^{235}U nuclei is about 4,5% per irradiation cycle (fluence of 7.8 10^{19} n.cm^{-2}).

As described here, our first approach consists of using the average current given by the detector as in saturation mode, that is to say:

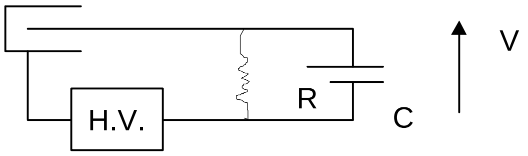
$$i = \overline{N}\overline{q} = \Phi_n \varepsilon \overline{q}$$

With:

i: average current (A)
$\overline{N}$: average number of events in the detector/s
$\overline{q}$: average charge per event (c)
Φ_n: thermal neutron flux (n.$cm^{-2}s^{-1}$)
ε: efficiency (A/n.$cm^{-2}s^{-1}$.C)

However, due to the low value of the applied voltage (30 V) we have to be sure that there is no shift of the efficiency. It is assumed using the fluctuation mode (i.e. Campbelling mode [6]) in the following manner.

From an electronic point of view, we have the next diagram:



With:

R: entrance resistance of the electronic amplifier (10^4 Ω)
C: capacity of the cable (≈ 1 pF)
HV: High Voltage (V)
V: measured signal (V)

If h(t) is the impulse response of the circuit; $h(t) = \frac{1}{C} e^{-t/RC}$

We can say (if $\overline{q}^2 >> \overline{q}^2$):

$$\overline{V} = \overline{N}\overline{q} \int_0^{+\infty} h(t)dt$$

$$\sigma_v^2 = \overline{N}\overline{q}^2 \int_0^{+\infty} h^2(t)dt$$

Consequently: $\frac{V^2}{\substack{2 \\ \sigma V}} = 2\overline{N}RC = 2RC\Phi_n\varepsilon$

or $\boxed{\Phi_n = \frac{V^2}{\substack{2 \\ \sigma V}} \bullet \frac{1}{2RC\varepsilon}}$

This second approach is under analysis at moment. The first results confirm the validity of the Campbelling mode and indicate the good complementarity between the two approaches.

The Self-Powered Neutron Detector

For the different irradiation levels, the SPND follow, very precisely, the value of the reactor power as indicated in Figure 5 which gives the thermal neutron flux versus the reactor power obtained by thermic assessment.

The acquisitions lead to the following results:

- The efficiency of Rhodium SPND is of 5,3 10^{-21} A/n.cm^{-2}s^{-1};
- The uncertainty on the thermal neutron flux evaluation is of 6% (at 2 standard deviation);
- There is a very good linearity between the thermal flux given by SPND and reactor power;
- There is no change in the SPND behaviour due to the temperature (the insulation resistance is of about 7 10^8 under neutron flux whatever the SPND – see Figure 5).

Conclusion

Such direct experiment is very fruitful in order to compare on-line the sensitivity and the behaviour of the major candidates for fixed in-core instrumentation. It can be said that the New Technology Fission Chamber looks promising in terms of sensitivity and uncertainty which are profitable compared to SPND. Nevertheless, this technology is more complex than the SPND one (need for power, risk of insulation leakage) in terms of reliability and robustness.

The second experiment planned in 1997 (VARAPPE device described earlier) will allow us to obtain, by the end of 1997, a global feasibility document including SMFC, slow and optimised prompt SPND.

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Figure 1. New technology sub-miniature fission chamber

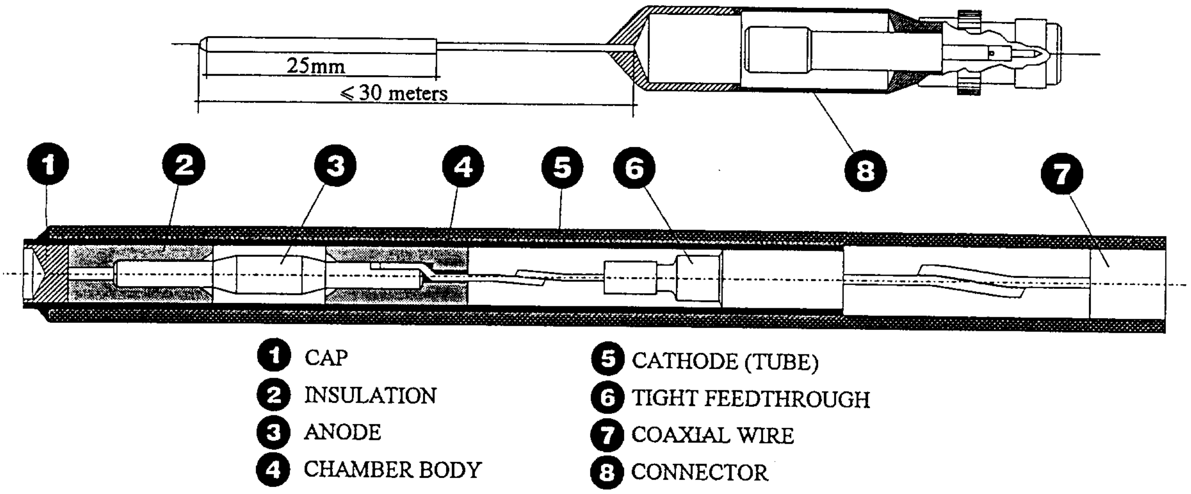

Figure 2. Schematic view of the CAFET device

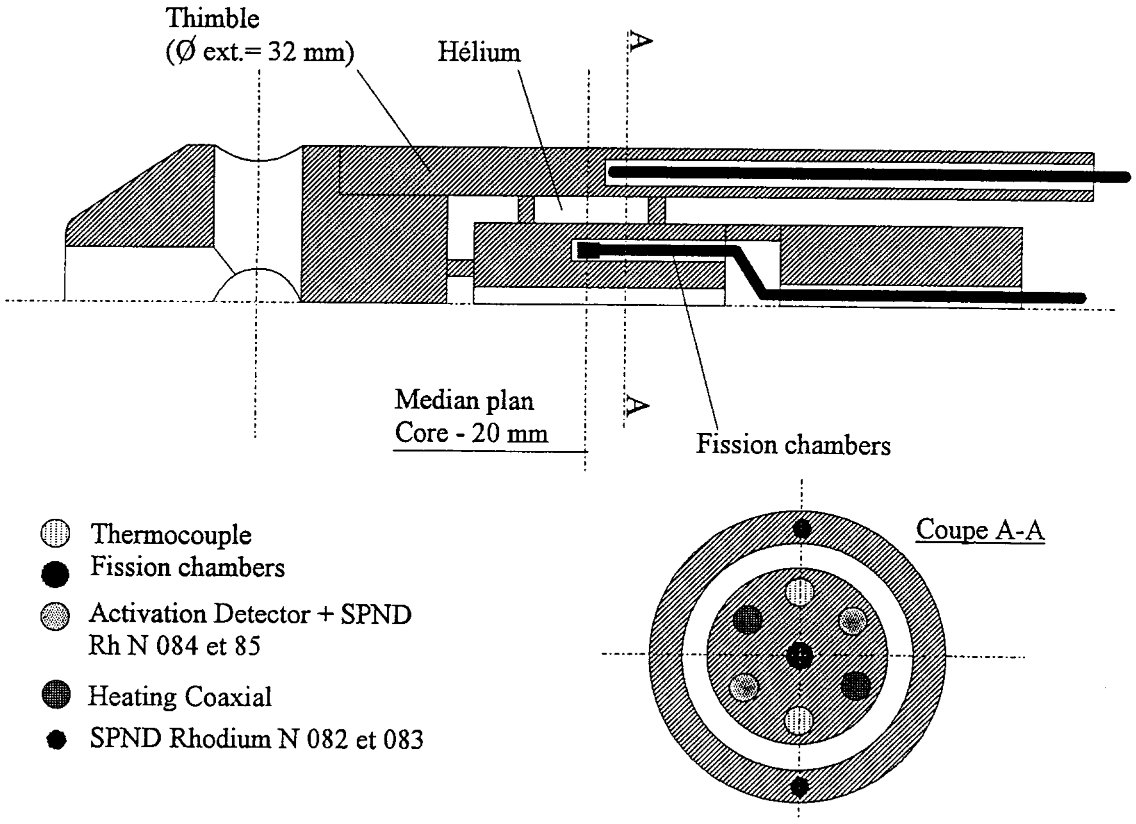

Figure 3. Schematic view of the VARAPPE device

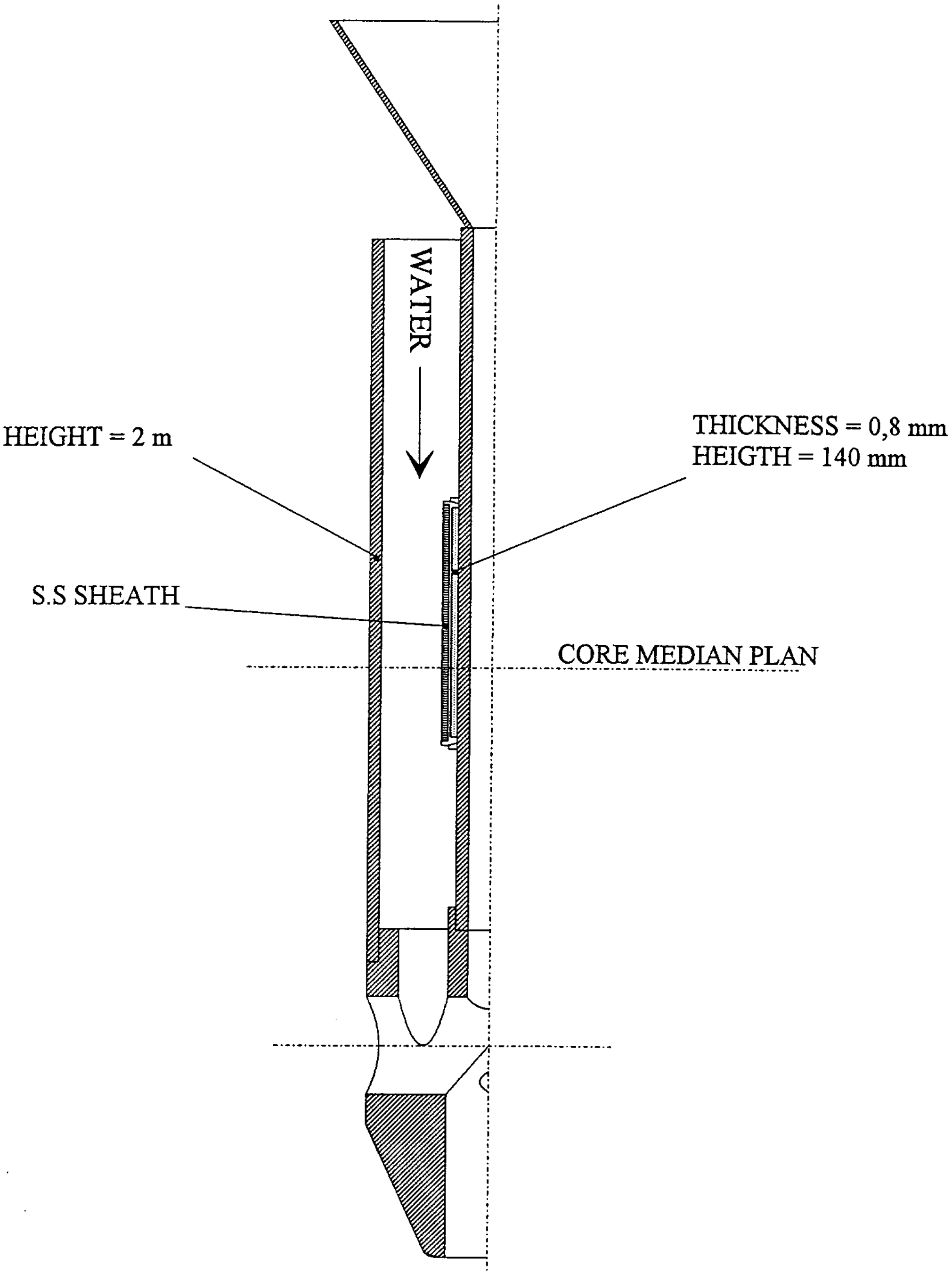

Figure 4. Average signal versus neutron flux for fission chambers n°1 and 2 (counting time 10s)

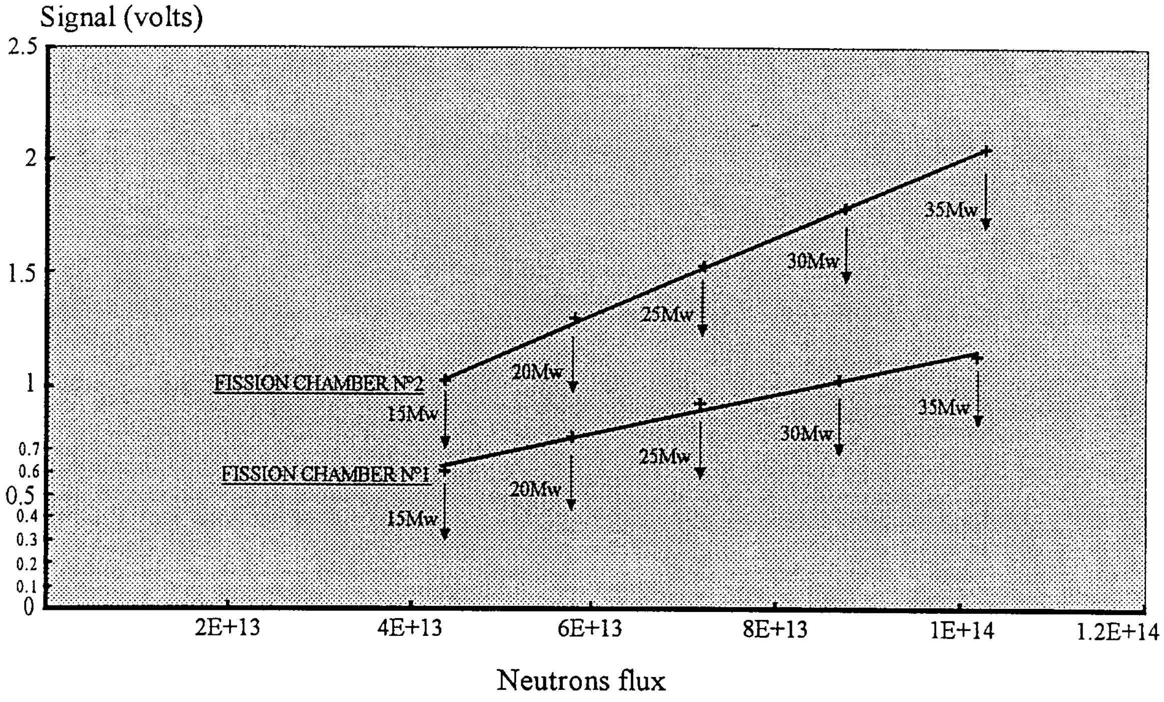

Figure 5. SPND responses